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A TEXTBOOK

ON

MARINE ENGINEERING

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

STEAM ENGINES
THE MACHINERY OF WESTERN RIVER STEAMBOATS
RECENT DEVELOPMENTS IN MARINE ENGINEERING
DYNAMOS AND MOTORS

WITH PRACTICAL QUESTIONS AND EXAMPLES

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STEAM ENGINES.

(PART 1.)

WORK AND EXPANSION OF STEAM.

934. Work Done by Steam.—Properly speaking, the steam does not do work; it acts merely as an agent, by means of which *heat* is transformed into work. Other agents, such as gas, air, petroleum, naphtha, etc., are often used for this purpose.

To gain a clear idea of the action of a steam engine, it must be carefully borne in mind that it is *heat*, not *steam*, that does work. It is customary, however, to speak of the "work done by the steam," "the work of expanding steam," etc., and these expressions, though not really true, will be used instead of the longer one, "the work done by the heat contained in the steam."

935. The usual method of obtaining work from heat is to generate steam at a high pressure by confining it in a closed boiler. This steam at pressures of from 75 up to as high as 200 lb. per sq. in. is then admitted to one end of a cylinder fitted with a piston, as shown in Fig. 253.

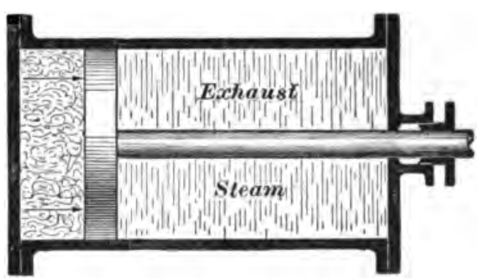


FIG. 253.

The left end of the cylinder is open to the entrance of steam from the boiler, and the right end is open to the atmosphere, so that the steam on the right side of the piston may escape freely. The pressure of the steam from the boiler will drive the piston to the right end of the cylinder, the steam on the right of the piston escaping into

the atmosphere. When the piston arrives at the right end of the cylinder, this end is put in communication with the boiler, and the left end with the atmosphere; the piston then moves back to the left end. The operation is thus repeated indefinitely.

The piston moves to the right because the pressure and temperature of the live steam on the left are greater than the pressure and temperature of the exhaust steam on the right of the piston. This means that the molecules of steam on the left are vibrating more rapidly than those on the right. The difference between the kinetic energy of the steam on the left and the steam on the right is, therefore, just equal to the work of moving the piston.

936. The work done in moving the piston from one end of the cylinder to the other may be found as follows:

Let P = the net pressure per *square foot* exerted on the piston. The net pressure is simply the difference of pressures on the two sides. Let A = area of piston in square feet. Let L = distance moved over by the piston, expressed in feet. Then, the total pressure on the piston is $P \times A$ pounds, and the distance this pressure moves through is L feet. Hence, according to rule **99**, Art. **541**, the work done = the force multiplied by the distance, or $P A \times L = P A L$ foot-pounds. But $A L$ = area of piston multiplied by the length of the stroke = the volume displaced by the piston during its movement from one end of the cylinder to the other. Let V represent this volume expressed in cubic feet. Then, letting W represent the work in foot-pounds, we have

$$W = P A L = P V.$$

937. It is more convenient usually to express our pressures in pounds per square inch instead of pounds per square foot.

Rule 169.—*To find the work done by a piston moving in a cylinder, multiply the net pressure on the piston in pounds per square inch by the volume displaced by the piston expressed in cubic feet, and multiply this product by 144. The result will be the work in foot-pounds.*

Let p represent the net pressure on the piston in pounds per square inch. Then,

$$P = 144\,p, \text{ and}$$
$$W = P\,V = 144\,p\,V.$$

The same result will be obtained by taking the pressure in pounds per square inch, multiplying by the volume in *cubic inches*, and dividing the result by 12.

EXAMPLE.—The piston of an engine is acted upon by a net pressure of 32½ lb. per sq. in. The volume swept over by the piston at each stroke is 5½ cubic feet. (*a*) How much work is done at each stroke? (*b*) If the engine makes 80 strokes per minute, what horsepower does it develop?

SOLUTION.—(*a*) According to rule **169**, the work is

$W = 144\,p\,V = 144 \times 32\frac{1}{2} \times 5\frac{1}{2} = 25{,}740$ foot-pounds. Ans.

(*b*) The number of foot-pounds per minute is $25{,}740 \times 80$, and the horsepower developed is, therefore, $\frac{25{,}740 \times 80}{33{,}000} = 62.4$ horsepower. Ans.

938. Work Diagrams.—The work done by a moving piston may be represented by a diagram drawn on paper.

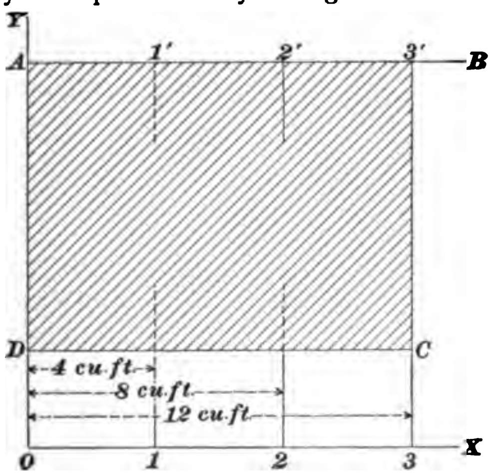


FIG. 254.

The manner of doing this is shown in Fig. 254. Two lines, $O\,X$ and $O\,Y$, are drawn at right angles. The line $O\,X$ is horizontal, and $O\,Y$ is vertical.

Suppose that the area of the piston is 2 square feet and the distance moved over by the piston is 6 feet. Then, when the piston has moved through a distance of one foot, it has displaced a volume of 2 cubic feet. On the line *O X* lay off a distance *O 1*, and let this distance be supposed to represent a piston travel of 2 feet. Then, the distance *O 2*, which is twice *O 1*, will represent a piston travel of 4 feet, and, similarly, the distance *O 3* will represent a travel of 6 feet.

Since the piston area does not change, the volumes swept through by the piston are proportional to the piston travel, and *O 1* may also be taken to represent the volume displaced by the piston when it has traveled 2 ft. That is, *O 1* will represent a volume of $2 \times 2 = 4$ cu. ft. *O 2* represents, likewise, 8 cu. ft., and *O 3*, 12 cu. ft. The piston is supposed to be moving from left to right; that is, in the direction *O X*.

When the piston is at the beginning of its travel—that is, at the position represented by *O Y*—lay off on the line *O Y* a distance *O A*, which to some scale represents the pressure on the left side of the piston. Suppose the pressure is 60 lb. per sq. in. Then, if *O A* is 2 inches, the scale is $\frac{60}{2} = 30$ lb. That is, a vertical height of 1 inch represents 30 lb. per sq. in. pressure. Suppose the pressure to be the same throughout the stroke of the piston. Then, when the piston is at the point represented by *1*, the pressure is represented by the distance *1-1'*, which is equal to *O A*. Likewise, when the piston is in positions *2* and *3*, the distances *2-2'* and *3-3'*, respectively, represent the pressures at those points. In brief, the pressure upon the left side of the piston at any position may be found by measuring the vertical distance between the lines *O X* and *A B* at that point and multiplying by the scale, 30 pounds per inch of height. In a similar manner, the pressure of the atmosphere on the right of the piston is laid off equal to the distance *O D*, which must, therefore, equal $\frac{14.7}{30} = .49$ inch Since this pressure on the

right of the cylinder is constant throughout the stroke, the line $D\ C$ parallel to the line $O\ X$ will represent it.

The net pressure on the piston is the difference between the pressures on the two sides, and is represented by the distance $D\ A\ (= O\ A - O\ D)$. We have shown that to some particular scale, $O\ 3 = D\ C$ represents the volume displaced by the piston. By rule **169** the work done by the piston is proportional to the net pressure multiplied by the volume. Now, on the diagram of Fig. 254, $D\ A$ represents the net pressure, and $D\ C$ the volume. But $D\ A \times D\ C =$ area $A\ B\ C\ D$. Hence, the area $A\ B\ C\ D$ must to some scale represent the work done by the piston.

By actual measurement $D\ A = 1.51$ inches; $D\ C = 2$ inches. Therefore, the area of the diagram is $1.51 \times 2 = 3.02$ sq. in. The scale of pressures adopted was 30 lb. per sq. in. = 1 inch. Hence, $p = 30 \times D\ A$. Since $D\ C\ (= 2$ inches) represents 12 cu. ft. of volume, the scale of volumes must be $\frac{12}{2} = 6$ cu. ft. per inch of length. Hence, $V = 6 \times D\ C$. Then, by rule **169,** the work done is

$$
\begin{aligned}
W &= 144\, p\, V = 144 \times (30 \times D\ A) \times (6 \times D\ C) \\
&= 144 \times 30 \times 6 \times (D\ A \times D\ C) \\
&= 144 \times 30 \times 6 \times 3.02 = 78{,}278.4 \text{ foot-pounds.}
\end{aligned}
$$

939. The diagram may be used in another way. The distances $O\ 1$, $O\ 2$, and $O\ 3$ may represent the distances moved through by the piston instead of the volumes displaced by it. Then, $D\ C$ will represent the stroke of the piston, in this case 6 ft., and since $D\ C = 2$ inches, the horizontal scale is $\frac{6}{2} = 3$ ft. of piston travel = 1 inch of length.

The work done is $W = 144\ p\ A\ L$. As before, $p = 30 \times D\ A$, $A = 2$ sq. ft., and $L = 3 \times D\ C$.

Hence, $W = 144 \times (30 \times D\ A) \times 2 \times (3 \times D\ C)$
$= 144 \times 30 \times 2 \times 3 \times (D\ A \times D\ C) = 78{,}278.4$ foot-pounds, as before.

The latter method is the one usually employed in con-

nection with indicator diagrams, which will be considered later on.

940. The above diagram is very simple because the pressure on both sides of the piston is constant throughout the stroke, thus making the diagram a rectangle. Suppose that the pressure decreases uniformly throughout the stroke, as shown in Fig. 255. Here the net pressure at the beginning of the stroke is represented by the distance $D\ A$, and at the end of the stroke by the distance $C\ B$. To calculate the work it is necessary to find the *average* net pressure throughout the stroke.

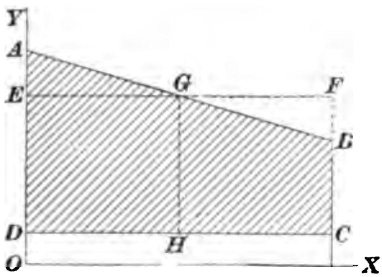


FIG. 255.

In this case the diagram is a trapezoid, and the average pressure is, therefore, represented by the line $H\ G = \frac{1}{2}(D\ A + C\ B)$. This distance $H\ G$ is called the **mean ordinate** of the diagram $A\ B\ C\ D$. It has such a length that when multiplied by the distance $D\ C$ it will give the area of a rectangle $E\ F\ C\ D$ which will be equal to the original area $A\ B\ C\ D$. The work performed is found by multiplying this mean ordinate by the length $D\ C$ by the scales of pressures and volumes, and by 144.

941. In Fig. 256 the line $A\ B$ represents the varying pressures on the left of the piston; or, more correctly, the pressures are represented by the distances between the lines $A\ B$ and $O\ X$. The pressures on the right of the piston are represented by the distances between the lines $B\ C$ and $O\ X$. Hence, the net pressures are represented by the vertical distances between the curved lines $A\ B$ and $B\ C$. The work done by the piston is, as in the above cases, represented by the area enclosed within the figure. To find the area of the figure we must find its *mean ordinate*. This may be done approximately in the following manner: Divide the length $O\ E$ of the diagram into a number of equal parts (10 or 20

parts are most convenient), and through each division draw a vertical line. Half way between these vertical

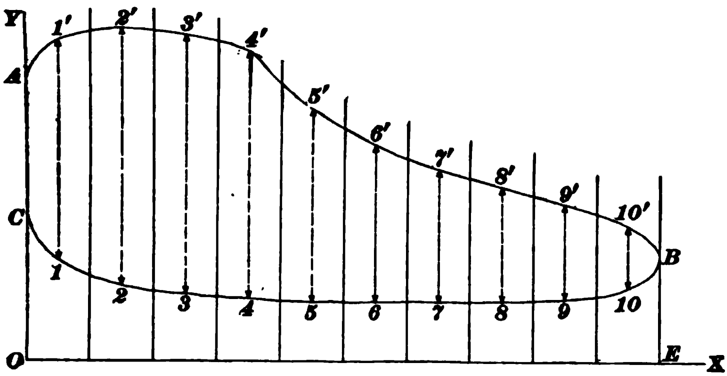


FIG. 256.

lines draw the lines *1-1'*, *2-2'*, *3-3'*, etc., extending between the lines $A\ B$ and $B\ C$. These vertical distances between the two curves are called **ordinates.** As shown in the figure, there are 10 of these ordinates equally distant from each other. If their lengths are all added together, and the sum divided by the number of ordinates, the result should be the average distance between the lines, or the **mean ordinate.**

942. The mean ordinate multiplied by the distance $O\ E$ will give the area of the diagram. Usually both the ordinate and $O\ E$ are measured in inches; the area will then be expressed in square inches. The area being found, the work performed is calculated by rule **169.** That is, *multiply the area by the vertical scale of pressures, by the horizontal scale of volumes and by 144. The result is the work performed during one stroke in foot-pounds.*

EXAMPLE.—The area of a diagram like that shown in Fig. 256 is found to be 7.34 sq. in. The vertical scale of pressure is 36 pounds equals one inch, and the horizontal scale of volumes is $2\frac{1}{4}$ cu. ft. equals one inch. What is the work per stroke of piston ?

SOLUTION.—Multiply the area by the horizontal and vertical scales and by 144, or work $= 7.34 \times 36 \times 2\frac{1}{4} \times 144 = 95,126.4$ ft.-lb. Ans.

EXAMPLES FOR PRACTICE.

1. The mean ordinate of a diagram similar to that shown in Fig. 256 is 1.2 inches long. The vertical scale of pressures is 1" = 40 lb. per sq. in., and the horizontal scale of distances is 1" = 10". The length of the diagram is 3", and 1 ft. of actual length of the vessel which contains the steam represents a volume of 452 cu. in. What is the work done in one stroke of the piston? Ans. 4,520 ft.-lb.

2. The mean pressure in the cylinder of a steam engine is 38.7 lb. per sq. in.; the diameter of the cylinder, 26"; the stroke, 32", and the number of strokes per minute, 120. Find the horsepower by means of rule **169.** Ans. 199.244 H. P.

3. The mean ordinate of a diagram is .89"; the length of the diagram, 3.2"; the vertical scale of pressures, 1" = 50 lb. per sq. in.; the horizontal scale of volumes, 1" (diagram) = .56 cu. ft. Find the work done in 12 strokes. Ans. 137,797.6 ft.-lb.

---

943. Expansion of Steam.—Suppose steam from a boiler enters a closed cylinder fitted with a piston, as shown in Fig. 253. If the cylinder is in communication with the boiler throughout the stroke of the piston, the pressure of the steam will be the same throughout the stroke, and the diagram of pressures will be a rectangle, as shown in Fig. 254. Suppose, now, that when the piston has completed say one third of its stroke, the communication between the cylinder and boiler is closed, and no more live steam is admitted. What will be the action of the steam already in the cylinder?

Since the pressure of the live steam on the left of the piston is greater than the atmospheric pressure on the other side, the piston will still be pushed along. But, since no more heat is supplied from the boiler, the work of pushing the piston must come from the heat contained in the steam already in the cylinder. Therefore, since heat is taken from the steam to do the work, its temperature must fall, and, consequently, its pressure must also fall as the piston moves along. For practical purposes, it may be assumed that the pressure falls according to Mariotte's law. (See Art. **593.**) That is, the pressure is assumed to vary inversely as the volume.

944. In connection with the diagram of Fig. 254, the piston area was taken as 2 sq. ft., and the length of stroke,

6 ft. Fig. 257 shows the pressure diagram on the supposition that steam from the boiler is shut off when the piston has traveled one-third of its stroke. Up to that point steam has entered from the boiler at a constant pressure, shown by the

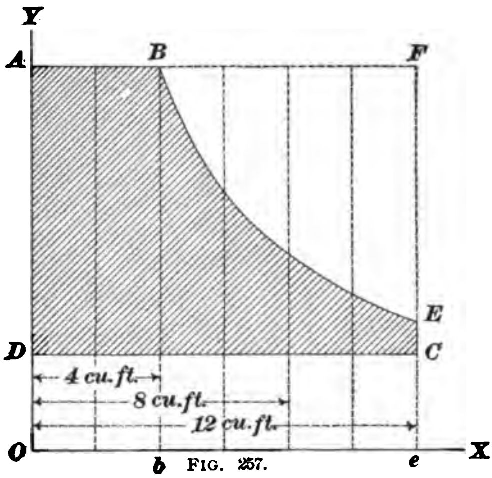


FIG. 257.

line $A\ B$. The volume of steam in the cylinder at this point is 4 cu. ft. As the piston moves forwards, the pressure begins to fall. When two-thirds of the stroke is completed, the steam which previously occupied 4 cu. ft. now occupies 8 cu. ft.; that is, its volume is doubled, and, by Mariotte's law, its pressure should be one-half what it was originally, or $\frac{1}{2}\ b\ B$. When the piston reaches the end of the stroke, the steam occupies 12 cu. ft., or 3 times its original volume. Therefore, its pressure is one-third the original pressure; that is, $e\ E = \frac{1}{3}\ b\ B$. The line $B\ E$ shows the gradual diminution of pressure during the last two-thirds of the stroke. When steam is shut off from the boiler in this manner, and does work at the expense of its own heat, it is said to be used **expansively.** The line $B\ E$, which shows the fall of pressure, is called the **expansion line.**

945. It was found that the area $A\ 3'\ C\ D$ of the diagram of Fig. 254 was 3.02 sq. in., and the work done per stroke of piston was 78,278.4 ft.-lb. The area of the diagram $A\ B\ E\ C\ D$,

Fig. 257, is nearly 1.82 sq. in. The work done per stroke is, therefore, $1.82 \times 30 \times 6 \times 144 = 47{,}174.4$ ft.-lb.

In the first case, 12 cu. ft. of steam were taken from the boiler, and the work per cubic foot was, therefore, $\frac{78{,}278.4}{12} = 6{,}523.2$ ft.-lb. In the second case, only 4 cu. ft. of steam were allowed to enter from the boiler. Consequently, the work done per cubic foot of steam was $\frac{47{,}174.4}{4} = 11{,}793.6$ ft.-lb., or nearly twice as much. This clearly shows the economy of cutting off the steam early in the stroke and allowing it to expand.

THE STEAM ENGINE.

946. It has been shown how steam may do work by lifting weights against the pressure of the atmosphere; since, however, it is not generally desired to do work in this manner, it is essential that some method of changing the to-and-fro or **reciprocating** motion of the piston into a continuous **rotary** motion be used. The form of mechanism used for this purpose in nearly all types of engines is shown

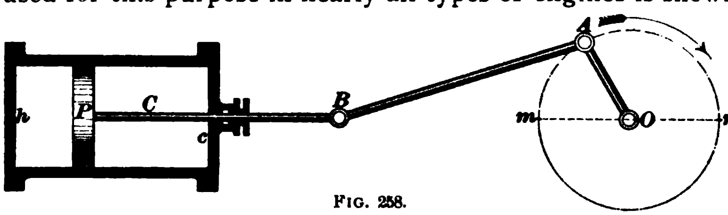


FIG. 258.

in Fig. 258. It is technically known as the **four-link slider crank.** The steam from the boiler enters one end —say, in this case, the end h—of the cylinder, and pushes the piston to the other end. By means of another mechanism called the *valve*, the steam is now admitted to the end c of the cylinder, while the end h is at the same time allowed to communicate with the atmosphere or with a condenser. The steam in h escapes, while that in c pushes the piston back again to its original position, whence the same operation is repeated.

947. Attached to the piston and forming a part of it is the piston rod $C B$; to the end of $C B$ is fastened, by a joint, one end of the link $B A$. The other end of $B A$ is joined to the link $A O$, and the other end of $A O$ terminates in a shaft O, which is fixed in stationary bearings. It is evident that the end of $B A$, which is attached to $C B$, can move only in a straight line; and since the shaft O can rotate only in its bearings, the end of $A O$, which is attached to $B A$, can move only in a circle.

When the piston is at one extreme end of the cylinder, say at h, the joint A is at the point m, and all three links $C B$, $B A$, and $A O$, lie in a straight line. As the piston moves to the right, the link $B C$ moves also to the right, while the joint A is constrained to move in the upper semicircle $m n$; when P arrives at the other end of the cylinder, the joint A is at n, and again $C B$, $B A$, and $A O$ are in a straight line. The piston now moves back to the end h of the cylinder, the joint A moving in the lower semicircle from n to m.

The link $C B$ is called the **piston rod**; $B A$, the **connecting-rod,** and $A O$, the **crank.** The piston, piston rod, cross-head, and guide blocks, and the front end of connecting-rod, together constitute the **reciprocating parts.**

948. Assuming the engine to be horizontal, the end h of the cylinder, furthest from the crank, is known as the **head end**; the end c, nearest to the crank, is known as the **crank end.** Invert the engine so that the axis of the cylinder is vertical, with the cylinder above the crank; then, the engine is called an **inverted vertical engine.** The end h of the cylinder is now called the **top end,** and the end c, the **bottom end.** The distance passed over by the piston during one-half of a revolution of the crank is called the **stroke,** and it is plainly equal to the diameter of the circle described by the end of the crank; that is, to the distance $m n$.

The engine may run in the direction shown by the arrow in the figure, or it may run in the reverse direction.

Assuming the engine to be horizontal, in the former case it is said to **run over,** and in the latter case to **run under.** The stroke from the head to the crank end of the cylinder—that is, from left to right in the figure—is called the **forward stroke**; the stroke from crank end to head end, the **return stroke.**

949. In the case of a vertical inverted screw propeller engine, if the crank turns in the direction of the hands of a watch (the observer is supposed to be looking towards the bow of the vessel), the engine is said to run **right-handed**; if the crank turns in the opposite direction, **left-handed.** If the piston is moving towards the crank-shaft, it is said to be making the **down stroke**; if moving away from the crank-shaft, the **up stroke.**

Any marine engine propelling the vessel forwards is said to be running **ahead,** or to be in the **forward motion**; if propelling the vessel backwards, it is said to be running **astern,** or to be in the **backing motion.**

The above simple mechanism perfectly fulfils the office of giving continuous motion in one direction. Either a paddle wheel or a pair of paddle wheels, or a screw propeller is fastened to the shaft O, by means of which devices the vessel is propelled in the desired direction.

EXPLANATION OF NAUTICAL TERMS.

950. Let Fig. 259 represent a plan view of a vessel. The forward part of the vessel is called the **bow,** the rear

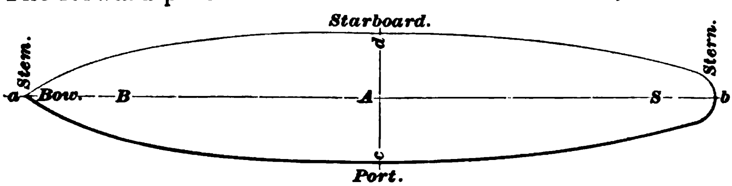


FIG. 259.

part, the **stern.** The forward extremity a of the vessel is known as the **stem.** An observer standing so as to be looking towards the bow has on his right the **starboard** side of the vessel, and on his left the **port** side. Anything

located near the center of the vessel, as at A, is said to be **amidship**; any object located near the bow, as at B, **forward**; if located near the stern, as at S, it is said to be **aft.** Any object placed so that its direction is parallel to the line $a\ b$ is said to be placed **fore and aft**; any object placed so that its direction is at right angles to the line $a\ b$, as the line $c\ d$, is said to have an **athwartship** direction. The width of a vessel is called its **beam.** The perpendicular distance from the lowest point of the vessel below the water-line to the surface of the water is known as the **draught**; it is expressed in feet and inches.

951. The **speed** of a vessel is usually expressed in knots per hour; the length of a knot being usually taken as 6,082 feet. Sometimes, however, the speed is expressed in miles per hour, counting 5,280 feet to the mile. In practice, the speed of a vessel is expressed as so many knots or miles. This is always understood to mean *per hour*, unless directly stated otherwise. The **displacement** of a vessel is equal to the weight of the water it displaces, and is usually expressed in tons. It will vary with the draught, for the deeper the vessel is in the water, the more water will it displace.

THE PLAIN SLIDE-VALVE ENGINE.

952. There are many types of the steam engine which may be classified as follows:

(1) According to the kind of service, as	Stationary, Locomotive, Marine, etc.
(2) According to number and arrangement of cylinders, as	Simple, Compound, Triple-expansion, Quadruple-expansion, Duplex, etc.
(3) According to the type of valve used, as	Plain slide valve, Automatic cut-off, Corliss, etc.

They may all be *horizontal* or *vertical*, *condensing* or *non-condensing*, *single-acting* or *double-acting*. All of these different types involve essentially the same principles, and, therefore, the description of a single type will be sufficient to give a general knowledge of those principles. For this purpose we shall choose the **simple slide-valve engine.**

953. In Fig. 260 such an engine is shown. Referring to the figure, *H* is the top end and *C* the bottom end of the steam cylinder; *B* and *B'* are the steam ports; *D* is the steam chest; *E* is the exhaust port; *N* and *N'* are the cylinder heads; *S* is the steam supply pipe; *O* is the exhaust pipe, connecting with the exhaust port *E*; *G* and *G'* are the two guides; *R* and *R'* are the shaft bearings, commonly known as the pillow-blocks; *T* is the bed-plate of the engine; *U* and *U'* are the columns on which the cylinder is supported. The above are all stationary parts of the engine, or parts which do not change their relative positions when the engine is in motion.

P is the piston; *b* is the piston rod; *Z* is the cross-head; *a* and *a'* are the wrist-pins, solid with *Z*, but not shown in section in the figure; *L* is the connecting-rod; *I* is the crank; *F* is the crank-pin; *A* is the crank-shaft; *K* and *K'* are the eccentrics; *J* and *J'* are the eccentric straps; *M* and *M'* are the eccentric-rods; *Y* is the link; *X* is the reach rod; *c* is the valve stem, and *V* is the slide valve. These are all movable parts, or parts which change their relative positions when the engine is in motion. *W* (Fig. 261) is the working length of the cylinder. It is slightly less than the distance between the cylinder heads, since a small space must be left between the head and the piston when the latter is at the end of its stroke. This space, together with the volume of the steam port which leads to it, is called the **clearance.**

954. The *stroke* of the engine is the travel of the piston *P*; since the piston and cross-head are rigidly fastened to the same rod, the stroke must also be equal to the travel of

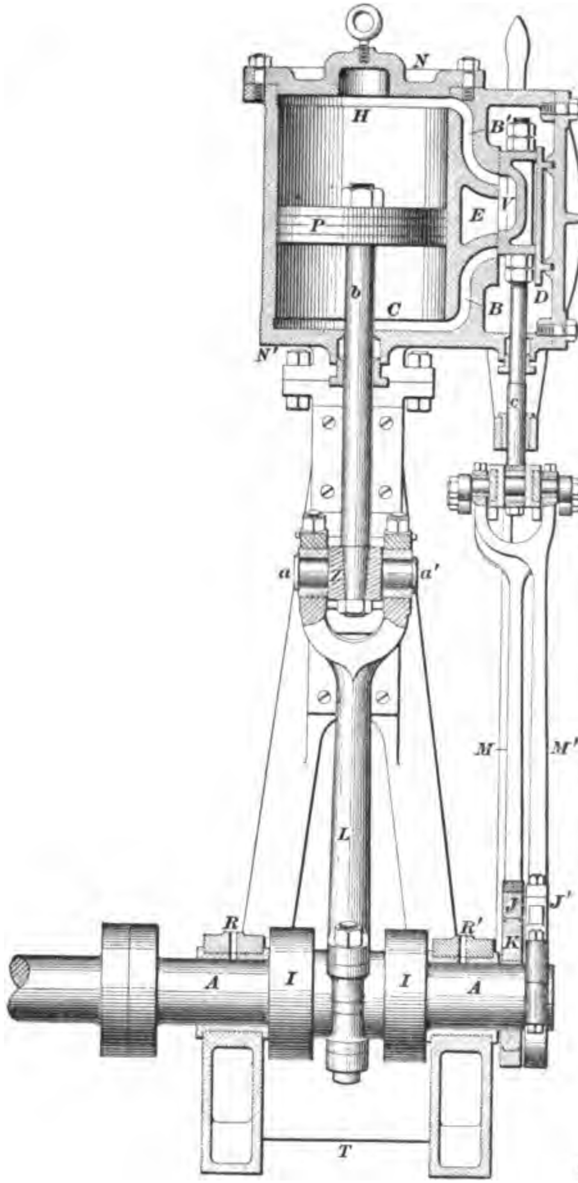
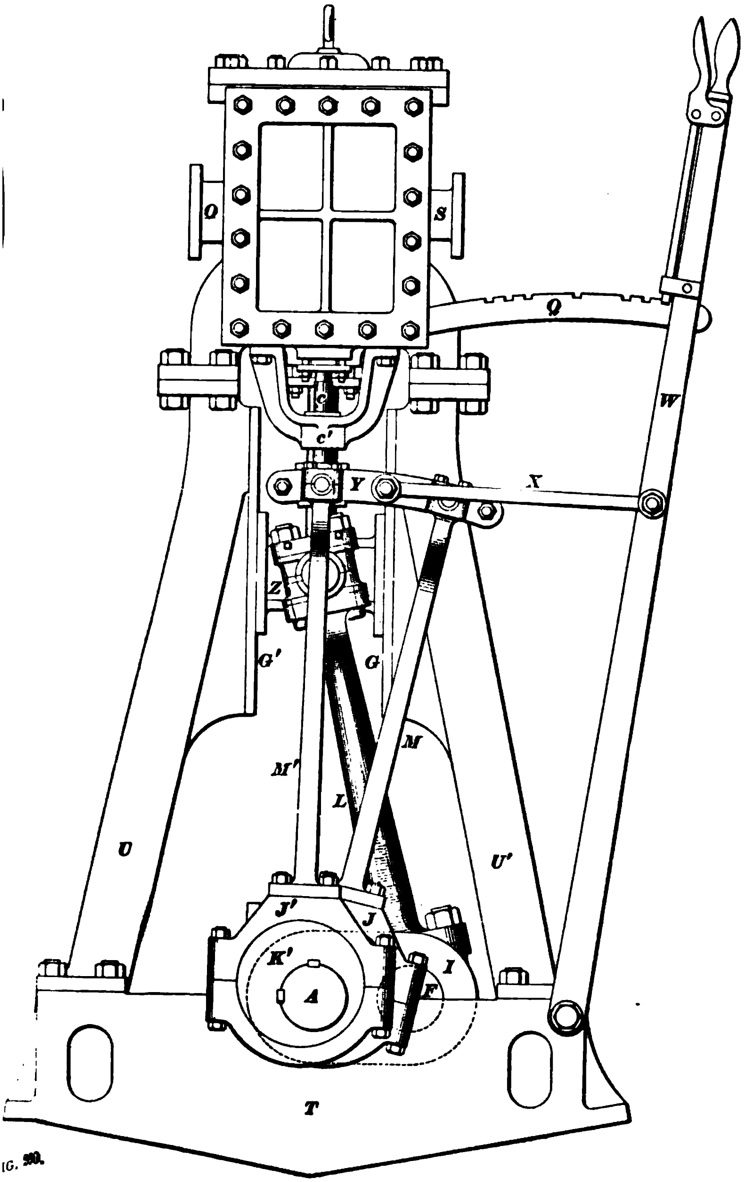


FIG.



IG. 300.

the cross-head. It was shown in Fig. 258 that the stroke is also equal to the diameter of the circle described by the

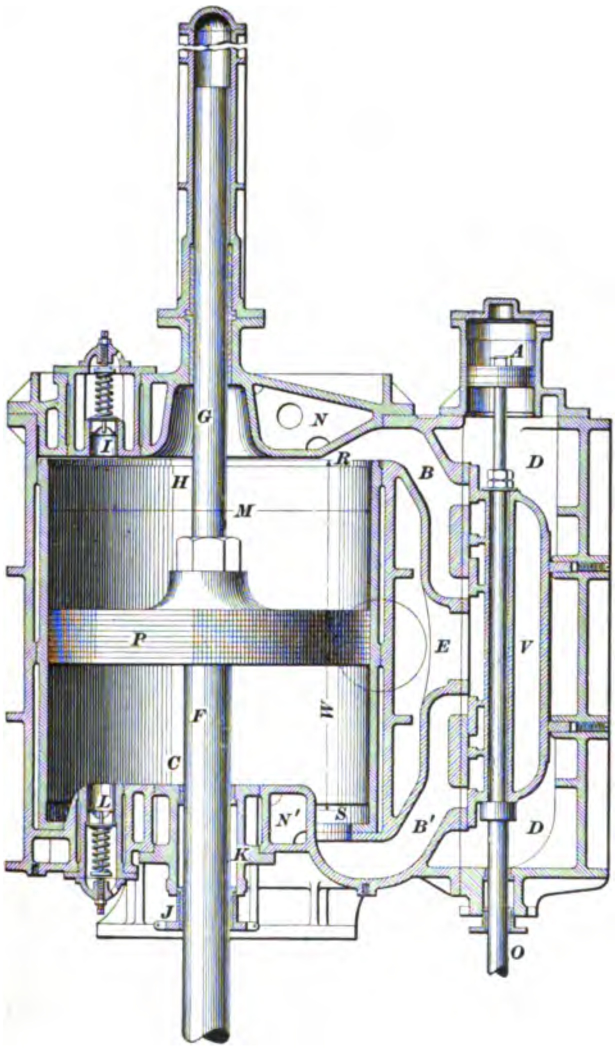


FIG. 261.

crank-pin F, or, what is the same thing, it is equal to double the length of the crank I, this length being measured from

the center of crank-pin *F* to the center of the crank-shaft *A*. *M*, Fig. 261, is the diameter, or **bore,** of the cylinder. The size of an engine is generally expressed by giving the diameter and stroke in inches, the diameter of the cylinder being always stated first. Thus, an engine having a cylinder diameter of 30 inches and a stroke of 36 inches is called a 30″ × 36″ engine.

955. At *R* and *S*, Fig. 261, the cylinder is **counterbored**; that is, for a short distance the bore is greater than *M*. The piston projects partly into this counterbore at the end of each stroke. Were it not for the counterbore the piston would not wear the cylinder walls their entire length, and shoulders would be formed at each end of the cylinder. When the wear of the joints in the connecting-rod is taken up, the length of the connecting-rod is slightly decreased, and the piston is pulled down slightly towards the bottom end of the cylinder. In this case the shoulder would cause an undesirable pounding of the piston.

Relief valves (*I* and *L*) are fitted to each end of the cylinder, through which any condensed steam may be discharged.

The piston fits loosely in the cylinder, and has split rings inserted, which spring out so as to press against the wall of the cylinder, and prevent leakage of steam between the wall of the cylinder and piston. The piston rod *F* (marked *b* in Fig. 260) is a round bar, rigidly connected to both the piston and cross-head. (See Fig. 260.)

In Fig. 261 *K* is a stuffing-box in which packing is placed; it is fitted with a gland *J*, which, when bolted down, compresses the packing around the piston rod *F*, and makes a steam-tight joint. Hemp packing was formerly used, plaited into rope form and having a core of tallow and graphite or soapstone; but this and the various vegetable packings are now generally replaced by some form of metallic packing. The high temperature of the steam used nowadays renders this necessary. When repacking, care

should be taken not to cause unnecessary friction by too much pressure from the gland.

G is the tailrod, which is guided in a bushing in the cylinder head *N*, and serves to steady the piston. Tailrods are not fitted to all engines. *A* is the balance cylinder for the slide valve *V*. Since large slide valves have an enormous weight, which would greatly increase the wear of the valve gear, it is customary to fit a balance cylinder to the valves if they are at all large. The balance cylinder is fitted with a close-fitting piston attached to the valve stem *O*; the upper end of the balance cylinder communicates with the condenser, while the steam pressure acts upon the under side of the piston. The balance cylinder is so proportioned that the force tending to push the piston upwards is equal to the weight of the valve. This practically counteracts the weight of the valve.

The cross-head *Z*, Fig. 260, is made an easy sliding fit between the guides *G* and *G'*, which are in line with the path of the piston rod; the piston rod is thus relieved of all bending stresses.

The connecting-rod *L* forms the connecting link between the cross-head and crank *I*. The joint between cross-head *Z* and connecting-rod *L* is made by the wrist-pins *a* and *a'*, and that between the connecting-rod and crank by the crank-pin *F*. Connecting-rods are usually made from 4 to 6 times the length of the crank, or from 4 to 6 "cranks" in length.

All the other reference letters in Fig. 261 correspond to those in Fig. 260.

956. In Fig. 262 one of a pair of eccentrics is shown. By means of the eccentrics, motion is imparted to the slide valve. The eccentric consists of a circular disk of iron *9*, which is keyed to the shaft and revolves with it. The center of this disk (which is called the **eccentric sheave**) is at *O*. As the shaft revolves, the center *O* of the sheave *9* will describe the dotted circle. Consequently, the eccentric strap *10* and the eccentric-rod *11*, to which it is fastened,

will be moved in the direction of the length of the rod, during a half revolution, a distance equal to the diameter *T* of the dotted circle.

This distance *T* is called the **throw of the eccentric.** The distance *O Q* between the center of eccentric and center

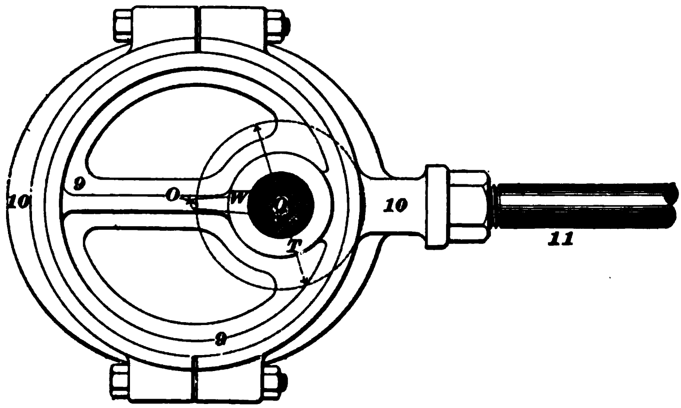


FIG. 262.

of shaft is called the **radius of the eccentric.** It will be seen that the **throw** is twice the **radius.** As shown in the figure, the eccentric sheave is rather large in proportion to the shaft. Usually the diameter of the shaft is greater than the throw of the eccentric.

957. It is also evident that the eccentric is equivalent to a crank, the length of which is equal to the radius of the eccentric. Thus, if the end of the eccentric-rod *11* were attached at *O* to the crank *W* (shown in dotted lines), the crank would give the same motion to the rod that the eccentric does. In plain slide-valve engines, the eccentric is usually keyed to the shaft after being properly adjusted. The connection between the eccentric-rod *M*, Fig. 260, and the valve stem *c*, is accomplished in a variety of ways, some of which will be described later on. In Fig. 260 a bracket *c'* is used to support the valve stem *c*. The latter must be supported in some such manner, in order to prevent it from binding in its stuffing-box.

THE D SLIDE VALVE AND STEAM DISTRIBUTION.

958. Of the different kinds of valves used to distribute the steam in the engine cylinder, the **D** slide valve is the most common. A section of such a valve is shown in Fig. 263, in its central position; *p*, *p* are the **steam ports;**

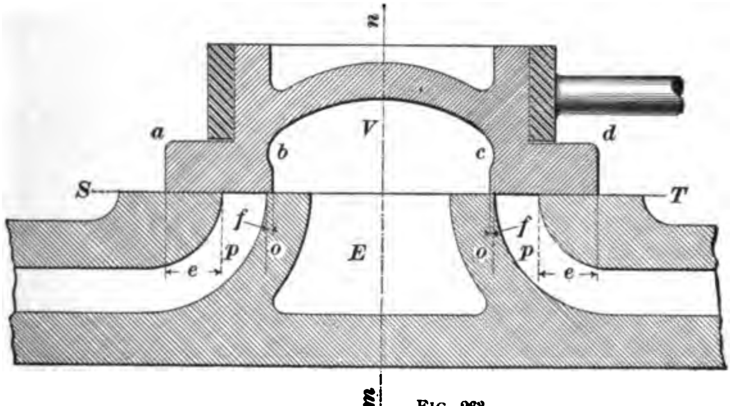


FIG. 263.

o, *o*, the **bridges;** *E*, the **exhaust port;** *S T*, the **valve seat.** The flanges of the valve, *a b* and *c d*, are seen to be wider than the ports which they cover. Of this extra width, the parts *e*, *e* are called the **outside lap,** and the parts *f*, *f*, the **inside lap.** The valve is here shown in mid-position; i. e., the center line *n* of the valve coincides with the center line *m* of the exhaust port.

The slide valves of marine engines are frequently constructed in such a manner that when placed in mid-position they do not cover the steam ports entirely; that is, the left-hand inner edge of the valve will be somewhat to the left of the edge of the left-hand bridge, and the right-hand inner edge of the valve will be somewhat to the right of the edge of the right-hand bridge. The distance between the inner edge of the valve and the bridge is then called **minus lap, negative lap,** or **inside clearance.**

959. Since the motion of the valve is governed by the eccentric, the valve is in mid-position when the radius of

the eccentric ($Q\ O$, Fig. 262) is at right angles to the center line of the eccentric-rod. When the center O of the sheave is in line with the center line of the eccentric-rod, and between the valve and the crank-shaft, the valve is in its position nearest to the top end (head end in case of a horizontal engine) of the steam chest; and when the center O is on the same line again, but at an angle of 180° with its former position—in other words, if the crank-shaft now lies between the valve and the center O, the valve is at the end of its stroke in the bottom end (crank end) of the steam chest. In order to show how the steam is distributed in the cylinder by means of the valve and eccentric, a series of skeleton diagrams of a horizontal non-reversible engine has been drawn, showing the relative positions of the valve and piston for different points of a double stroke.

960. Fig. 264 shows five of these diagrams. They represent a **D** slide valve without lap or lead. $O\ a$ represents the crank; $O\ b$, the eccentric (which has been shown to be equivalent to a crank); $a\ c$, the connecting-rod, and $b\ d$, the eccentric-rod. It should be remarked that the sizes of some of the various parts have, for the sake of clearness, been greatly exaggerated, particularly the radius of the eccentric circle, and the amount of clearance. Diagram A, Fig. 264, represents the piston as just on the point of beginning the forward stroke. The valve is moving in the direction of the arrow, and the outer edge is just about to admit steam to the left-hand port. As will be seen, the valve is in its central position, and, consequently, the line joining the center of the shaft and the center of the eccentric (this line will hereafter be called the eccentric radius) is vertical, the eccentric, in fact, being set 90° ahead of the crank. All of the parts are about to move in the direction of the arrows. Diagram B shows the position of the parts when the crank has moved through 90° from its position in diagram A. The piston is at the middle of its stroke, or very nearly in that position, having, in fact, traveled a short distance beyond the mid-position, owing to the fact that the connect-

ing-rod makes an angle with the line of stroke; but for this fact the piston would be at mid-stroke.

The angularity of the connecting-rod, however, will be

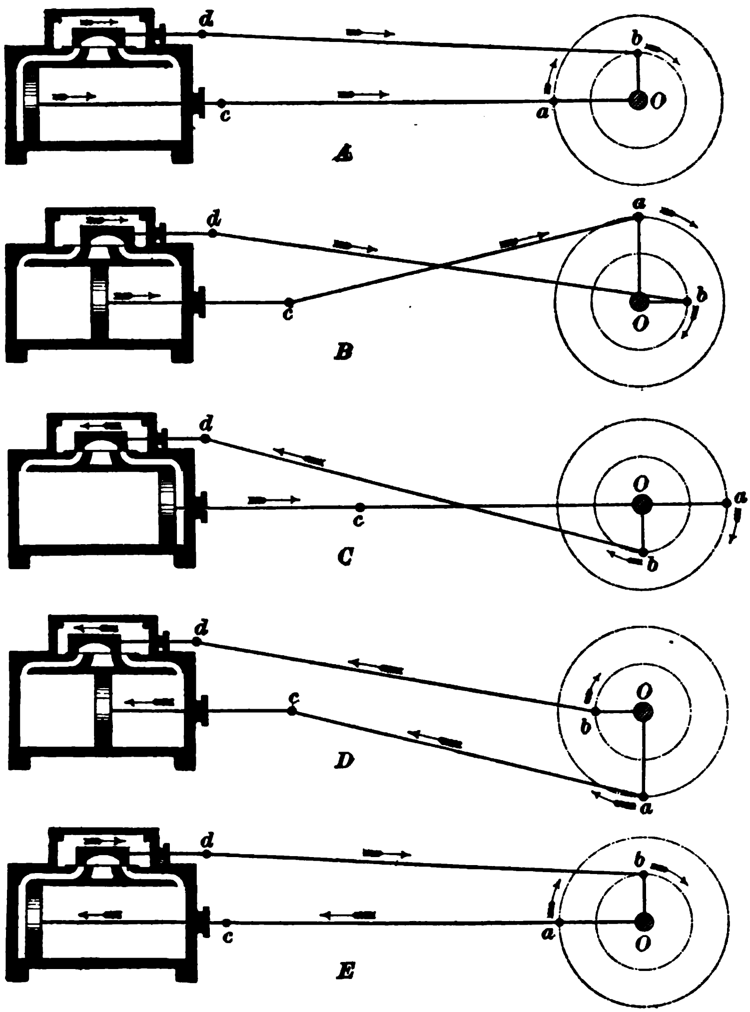


FIG. 264.

treated of later; for the present, it will be assumed that it has no effect on the position of the piston. The valve has

reached the extreme limit of its travel to the right, and the eccentric radius $O\ b$ is horizontal. The left steam port is fully opened for the live steam, and the right steam port is fully opened for exhaust. Another crank movement of 90° places the different parts as shown in diagram C. The piston has reached the end of its forward stroke; the valve is in its central position moving towards the left, and has just closed both ports—the left to the live steam and the right to the exhaust, and is just about to open the right port for admission of live steam and the left port for the steam to exhaust. The piston has now traveled one full stroke. Diagram D shows the piston in its central position on the return stroke. The crank is in the position $O\ a$; the eccentric radius is horizontal, as represented by $O\ b$, and the valve is at the farthest point of its travel to the left, the right port being fully open for live steam, and the left port fully open for exhaust. In the diagram E, the piston has reached the extreme point of the return stroke, the piston rod, the connecting-rod and crank being all in one straight line; this also occurs in diagram A (which is the same as E) and in C. The valve has been moving to the right, and is now in its central position, just on the point of admitting steam to the left port.

961. These diagrams show conclusively that, with no lap or lead, the steam is admitted to the cylinder for the full stroke of the engine; consequently, there can be no cut-off, and, therefore, no expansion of steam.

The following conclusion is now evident: *With an ordinary* **D** *slide valve, operated by one eccentric, there can be no cut-off, and, therefore, no expansion of steam, unless the valve has outside lap.*

The movements of the eccentric and crank, and also the effect of lap on the distribution of the steam, are clearly shown in Figs. 265 to 272. In these figures the valve has both outside and inside lap, but no lead. These diagrams have been exaggerated, as was done in Fig. 264, in order that the eccentric radius might be long enough to show up well. In

Figs. 265 to 272 the eccentric radius is three times as long as it should be for the amount of valve movement shown by the figure. The diameter of the crank circle is also a little greater than the stroke of the piston, for the same reason. In order to show the distribution of steam by the valve, a diagram has been drawn above and below each cylinder, those above being marked *M*, and those below *N*. These diagrams are supposed to be drawn in the following manner: Imagine it to be possible to connect two small pipes to the piston, one on each side. Suppose that each pipe has a steam-tight piston working in it, the lower side of the piston being subjected to the steam pressure in the cylinder, and the upper side to the atmospheric pressure. Suppose, further, that there is a coiled spring on top of the piston, and that a piston rod with a pencil attached to its end, at right angles, passes through the center of the spring. If a pressure of 10 lb. is required to compress the spring 1 inch, then, for every 10 pounds pressure in the cylinder, the pencil will move upwards 1 inch, and if in contact with a sheet of paper, will mark a line on that paper. It will now be assumed that an arrangement like that just described is attached to each side of the steam-engine piston, and that the pencil touches a sheet of paper that is held stationary. Then, when the steam piston moves ahead, the pencils will make straight lines at heights corresponding to the steam pressure on the under sides of the small pistons, except when the pressure of the steam in the cylinder varies, in which case the pencil will move up or down, according as the pressure increases or diminishes.

962. Having made these suppositions clear, let *X Q*, Figs. 265 to 272, represent the line which the pencil would trace if there were a perfect vacuum in the cylinder; i. e., *X Q* is the line of no pressure; also, let *A B* represent the line which the pencil would trace if the pressure in the cylinder were just equal to that of the atmosphere, and let *Q Y* represent the line of no volume. Then, the point *Q* represents no volume and no pressure. Finally, let *1 D*, the dis-

tance between lines *A 1* and *Q Y*, represent the volume of the clearance.

963. Consider now Fig. 265. The piston is represented as just beginning the forward stroke, and the valve as just commencing to open the left steam port, both moving in the same direction, as shown by the arrows. If the valve had no outside lap, the position of the eccentric center would

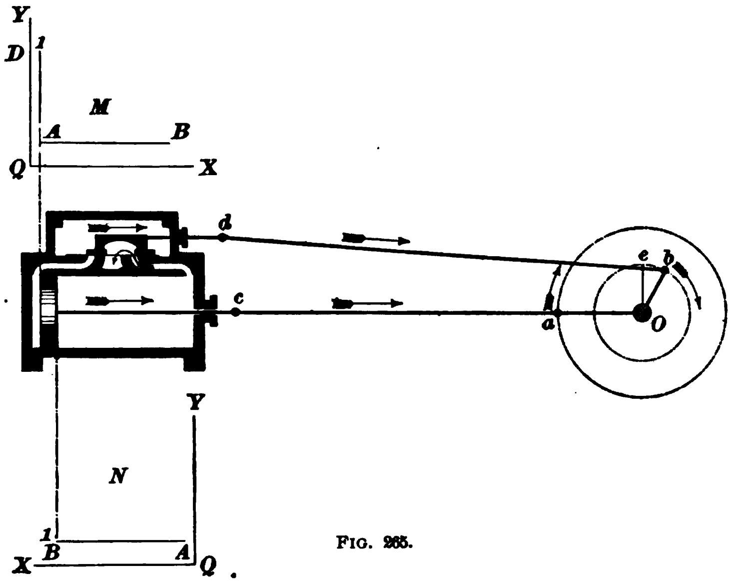


FIG. 265.

be at *e*, but on account of the lap, the valve has had to be moved ahead of its central position, in order to bring its edge to the edge of the port. To accomplish this, the eccentric center has been moved from *e* to *b*, *O b* being the position of the eccentric radius. The angle *b O e*, which the eccentric radius now makes with the position it would be in if there were no lap or lead, is called the **angle of advance.**

Assume that the piston and valve have moved a very small distance, just sufficient to admit steam to fill the clearance space on the left of the piston, so that the steam acts on the piston at full boiler pressure. If the length of

the line *A 1* represents the boiler pressure as shown on the gauge, the pencil which registers the pressure on the left side of the piston will be at *1*. The steam on the right side of the piston is exhausting into the atmosphere through the exhaust port as shown by the arrow. As the size of the

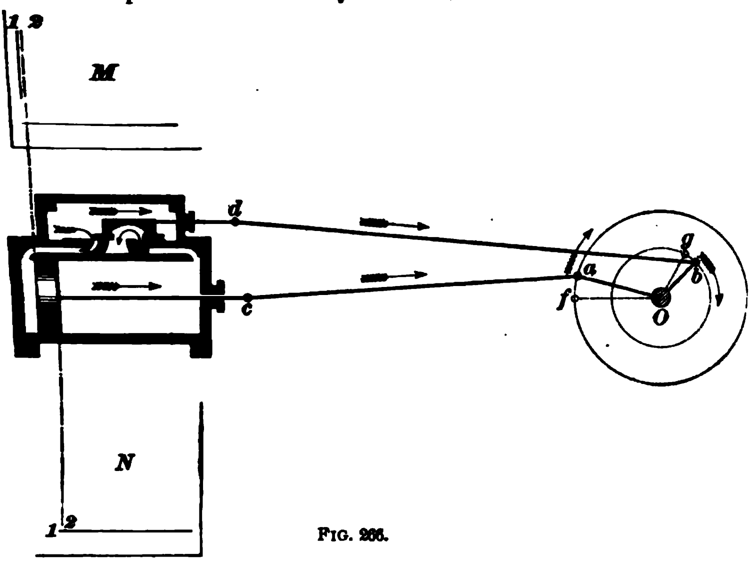


FIG. 266.

exhaust port is limited by practical considerations, the exhaust is not perfectly free, and there is a slight pressure on the exhaust side of the piston in addition to the atmospheric pressure. This is termed **back pressure.** Therefore, in the diagram *N*, let *1* be the position of the second pencil, then *B 1* represents the back pressure.

964. Fig. 266 shows the position of the piston and valve when the exhaust port is fully open. The crank has moved from the position *O f* (shown by dotted line) to *O a*, and the eccentric center from *g* to *b*. Steam is entering the head end of the cylinder and exhausting at the crank end. The pencils have moved from *1* to *2* on both diagrams *M* and *N*.

The dotted line extending up into the space *M* is supposed to represent the small piston rod with the pencil attached to its end, thus registering the pressure on the left side of

the piston; similarly, the dotted line below the cylinder represents the other small piston rod and registers the pressure on the right side of the piston.

965. In Fig. 267 the piston has advanced far enough to enable the valve to reach the end of its stroke and open

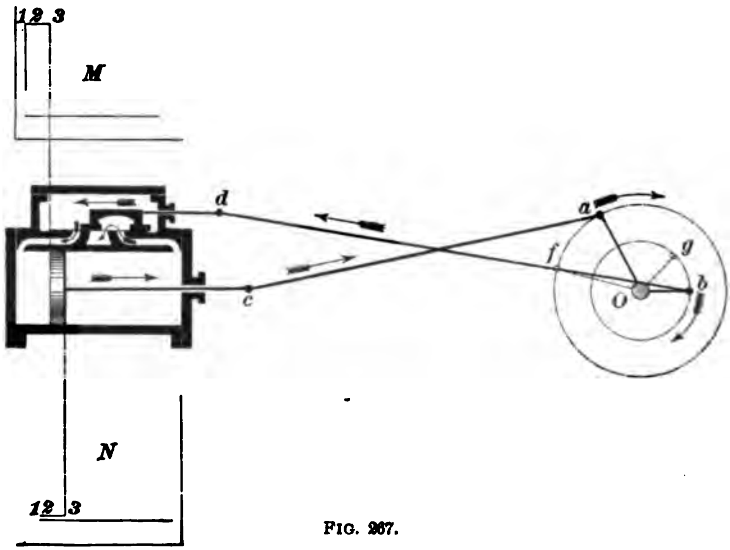


FIG. 267.

the port its full width. The crank and eccentric have moved to the positions *O a* and *O b*, the dotted lines showing their last positions in Fig. 266. The eccentric radius is horizontal, and any further movement of the crank will cause the eccentric to travel in the lower half of its circle, and make the valve move back. In the diagrams *M* and *N*, the pencil has traced the lines *2-3*.

966. Fig. 268 shows the piston still further advanced on its stroke, and the valve as having its inside edge in line with the outside edge of the exhaust port. The left end of the valve has partially closed the steam port. The amount of advancement of the crank and eccentric, from their last positions, is shown by their distances from the dotted lines. The pencils have traced the lines *3-4* on the diagrams *M* and *N* during this movement of the piston from the last position.

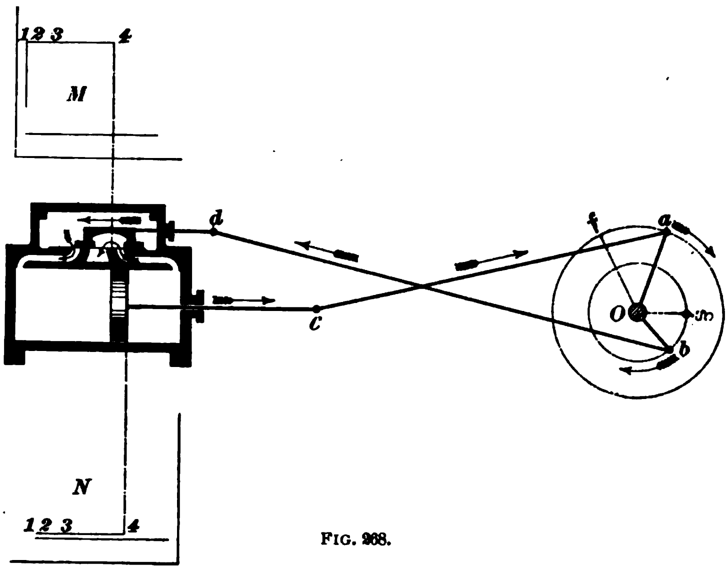


FIG. 268.

967. Fig. 269 marks one of the most important points of the stroke. Here the valve has closed the steam port,

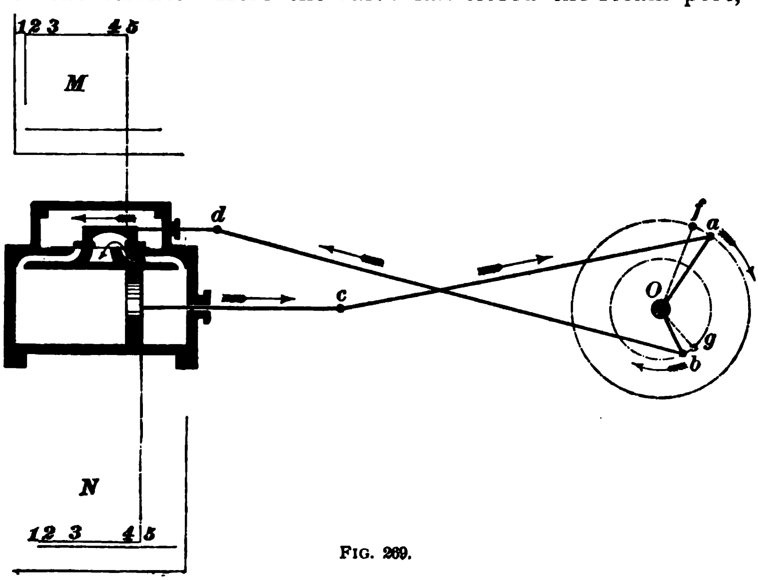


FIG. 269.

i. e., cut off the steam, and from here to the end of the stroke, the steam in the cylinder expands. This is called the point of **cut-off.** The exhaust port is now partially closed. The crank and eccentric have moved through the angles indicated. During this movement the pencils have traced the lines *4-5*.

968. Fig. 270 shows another very important valve position. Here the inside edge of the valve closes the exhaust port, and from now on to the end of the stroke, the steam

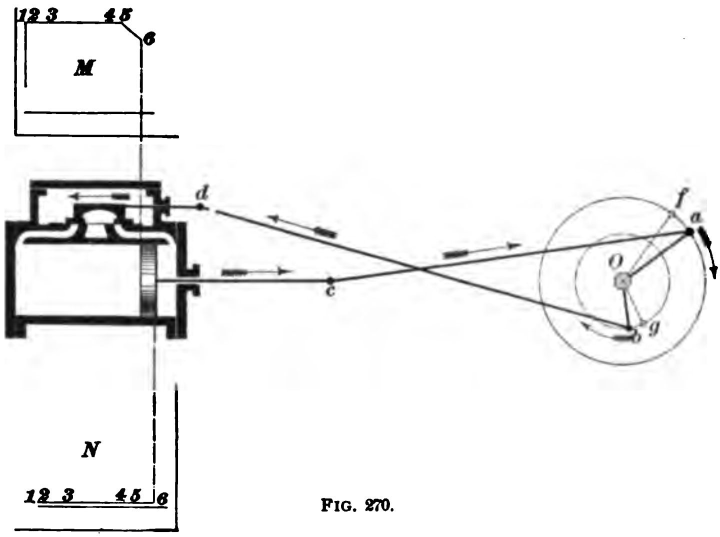


FIG. 270.

in front of the piston is compressed. This point in the stroke is called the point of **compression.** In the diagrams *M* and *N*, the lines *5-6* are traced by the pencils. The line *5-6* on the diagram *M* is an expansion line, the pressure falling as the piston moves ahead.

969. In Fig. 271 the piston has advanced far enough to cause the left inside edge of the valve to be in line with the inside edge of the left port. The slightest additional movement of the valve to the left will open the left port so that the steam in the left end of the cylinder will pass into the exhaust port. This point of the stroke is called the point of

release. The work performed by the piston due to the expanding steam is supposed to end here, owing to communication being made with the atmosphere, but owing to the limited size (and also the indirectness) of the ports, there will still

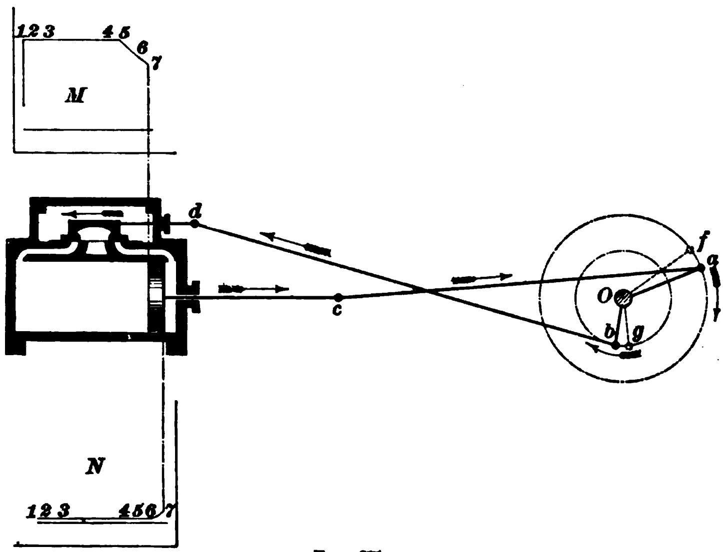


FIG. 271.

remain some pressure on the piston, and, therefore, some additional work will be done. During this last movement of the piston, the pencils traced the lines *6-7* on the diagrams *M* and *N*. On the diagram *M* the line *6-7* is a continuation of the expansion line *5-6*, while in the diagram *N* it shows part of the compression line, the pressure rapidly increasing as the piston nears the end of the stroke.

970. In Fig. 272 the piston has reached the end of its forward stroke, and is about to begin the return stroke. The right outside edge of the valve is in line with the outside edge of the right port. The steam is exhausting from the head end of the cylinder, as shown by the arrow. The crank and eccentric are both diametrically opposite their positions in Fig. 265. In the diagrams *M* and *N*, the pencils have traced the lines *7-8*. *M* shows that the pressure

has fallen very rapidly from *7* to *8*, while in *N* it has risen from *7* to *8*. The very slightest movement of the piston to the left will admit steam to the crank end of the cylinder and cause the pencil to rise to the point *1'*.

During the return stroke the above described actions of the steam will be repeated, the pencils tracing the dotted

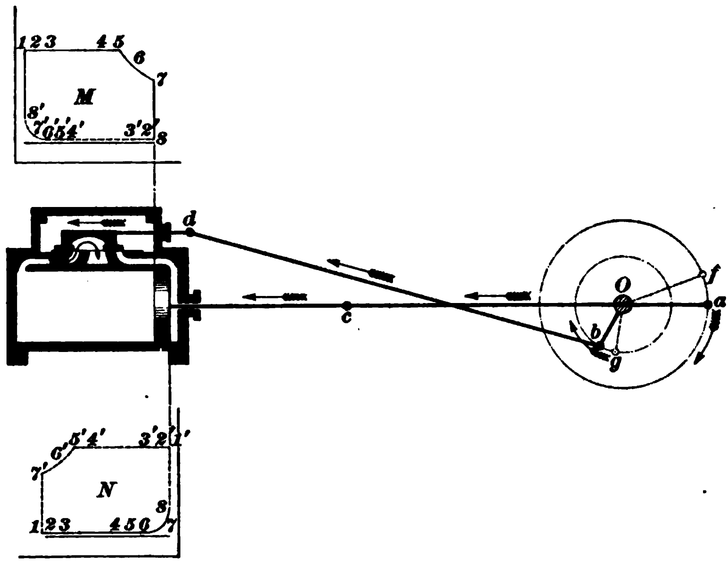


FIG. 272.

lines on the diagrams *M* and *N* in Fig. 272, the exhaust steam going through the left port, and the incoming steam through the right port. As the process is so nearly like the preceding, the diagrams have not been drawn, but the student should follow the valve through the different positions, and note the effects on the diagrams. To assist him in this, the corresponding points have been numbered, as in the foregoing figures.

971. Effects of Lap.—A study of Figs. 265 to 272 will show the effects caused by varying the lap. Thus, in Fig. 269, it is evident that if the outside lap had been less, the valve would not close the left port when its center was in the position shown; consequently, the piston must move

further ahead before the valve can move back far enough to close the port. This, of course, makes the cut-off take place later in the stroke, and shortens the expansion. It is likewise evident that if the valve had more lap, this extra lap would extend beyond the port when the center of the valve was in the position shown. Therefore, the valve would cut off earlier in the stroke and the expansion would be lengthened. Hence, *increasing the outside lap means an earlier cut-off and an increasing expansion, while decreasing the outside lap means a later cut-off and a diminished expansion.*

If the outside lap be increased, the cut-off may still be kept constant by decreasing the angle of advance.

972. As regards the effect of inside lap, it is evident, from Fig. 270, that if the lap had been less, the exhaust port would not have closed so soon, and, consequently, the compression would have begun later; had the inside lap been greater, the compression would have begun earlier. Fig. 271 shows that with a diminished inside lap, the release would begin earlier, while, with an increased inside lap, the release would have taken place later in the stroke. *Increasing the inside lap causes the compression to begin earlier in the stroke, and causes the release to take place later.* On the other hand, *diminishing the inside lap or giving negative lap causes the compression to begin later, and the release to take place earlier in the stroke.*

973. Lead.—In Fig. 265 the piston is just commencing the forward stroke, and the valve is just about to uncover the left steam port. Most engineers, however, prefer to have the port open a little when the piston is at the end of the stroke. That is, the valve, instead of being just at the edge of the port, as shown in Fig. 265, is moved $\frac{1}{16}''$ or $\frac{1}{8}''$ to the right, so that the clearance space is filled with fresh steam before the piston begins its stroke. In marine engines more "cushion" is required at the bottom, or crank end, of cylinder than at the top end, on account of the weight of the moving parts (piston, rod, etc.), so that it is customary

to give nearly twice as much lead on the bottom as on the top end. A valve with lead is shown in Fig. 273. Here the

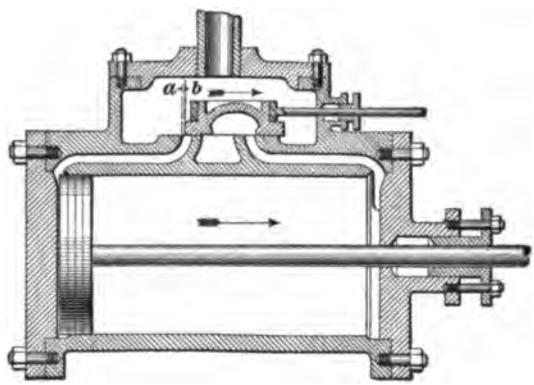


FIG. 273.

piston is at the end of the stroke, and the port is open a distance *a b*. This distance *a b* is the **lead.**

Since, when a valve has lead, it is moved further to the right than in the position shown in Fig. 265, it is evident that the center *b* of the eccentric must also be moved a little further to the right (Fig. 265). That is, to give a valve lead, or to increase the lead that a valve may already have, the angle of advance must be increased.

974. Position of the Eccentric.—When the plain slide valve has no lap or lead, as in the skeleton diagrams, Fig. 264, it has been shown that the eccentric must make an angle of 90° with the crank. Further, when the engine "runs over," as shown in the diagram, Fig. 264, the eccentric is *ahead* of the crank. That is, following the direction of the arrows, the eccentric *b* reaches any point on its circle a quarter of a revolution before the crank *a* does. Referring now to Figs. 265 to 272, it is seen that when the valve has lap (or lap and lead), the angle *a O b* between crank and eccentric is greater than 90°. Following the direction of the arrows, it is seen, however, that the eccentric *b* reaches say the lowest point on its circle earlier than the crank *a*

reaches the lowest point on its circle. That is, the eccentric is *ahead* of the crank, as in the above case.

975. Take now the case of an engine that "runs under," as shown in Fig. 274. The crank is in position a, and is about to move downwards. Now, the eccentric can not be in the position $O\ b'$, for then it would move the valve to the left. It can not be opposite, in the position $O\ g$, for in that case the valve would not be far enough to the right. It must be in the position $O\ b$. An inspection of the diagram

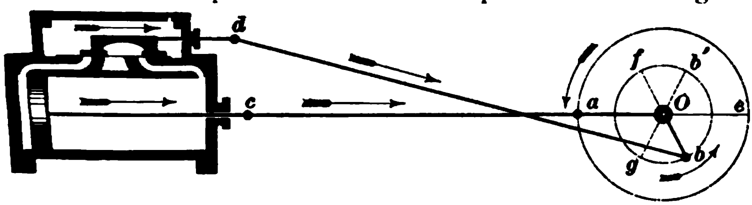


FIG. 274.

shows that, following the direction of the arrows, the eccentric in this case also is set *ahead* of the crank, and the angle between the crank and eccentric is $a\ O\ b = 90° +$ angle of advance.

Hence, for the ordinary slide valve, the following general rule applies:

When the valve rod and eccentric-rod move in the same direction, the eccentric is set **ahead** *of the crank, and the angle between the crank and eccentric is 90° + the angle of advance.* This law is true whether the engine runs "over" or "under," "right-handed" or "left-handed."

976. Rocker-Arms.—It frequently happens that the eccentric can not be so located on the shaft (in the direction of its length) that the eccentric-rod and valve stem shall be in the same straight line. It can never be done when the valve is on top of the cylinder (in case of a horizontal engine) or on the port or starboard side of the cylinder of a vertical engine, without inclining the valve seat, now very seldom done; and in case of a horizontal engine, as often used for auxiliary purposes, with the valve on the side of the cylinder, other considerations, such as the location of the fly-wheel,

may interfere. In such cases as this, a lever or rocker-arm may be employed.

An example is shown in Fig. 275. It is evident that, when the eccentric-rod *a* moves to the left, the valve rod *b* will also move to the left, being compelled to do so by the

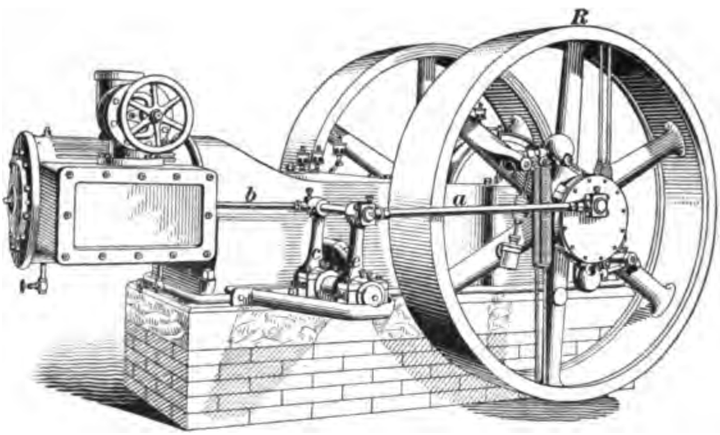


FIG. 275.

rocker and its arms *c*, *e*. It is also plain that the amount of horizontal movement of the valve rod will also be the same as it would be if the eccentric were attached directly to the valve rod, thus getting rid of the rocker-arms. The reason for using the rocker in this case is that the eccentric-rod axis and valve-stem axis are not in the same straight line, the presence of the fly-wheel necessitating the setting out of the eccentric to the right. The valve seat could, in this case, have been placed further out from the center of the cylinder, so as to bring the axes of the two rods in line. This, however, would have made the steam and exhaust ports that much longer; therefore, as it is an advantage to have ports as short as possible, a rocker-arm was used.

Again, it is sometimes desirable to make the throw of the eccentric less than the valve travel. This may be accomplished by the use of a rocker-arm, as shown in Fig. 276. The rocker is pivoted at *g* and rotates about that point as a center. The valve rod is joined to the valve stem at *f* and

to the rocker at the end *e*, the eccentric-rod being joined to the rocker at *d*, a point between *e* and *g*.

Then, the eccentric throw must be smaller than the valve travel in the ratio $gd : ge \left(= \frac{gd}{ge}\right)$. For example, suppose the valve travel to be 4 inches, the distance $gd = 12$ inches and $ge = 15$ inches. Then, the throw of the eccentric $=$ 4 inches $\times \frac{gd}{ge} = 4 \times \frac{12}{15} = 3.2$ inches.

When the rocker is arranged as in Fig. 276, whether the engine runs over, as in the upper figure, or under, as in the

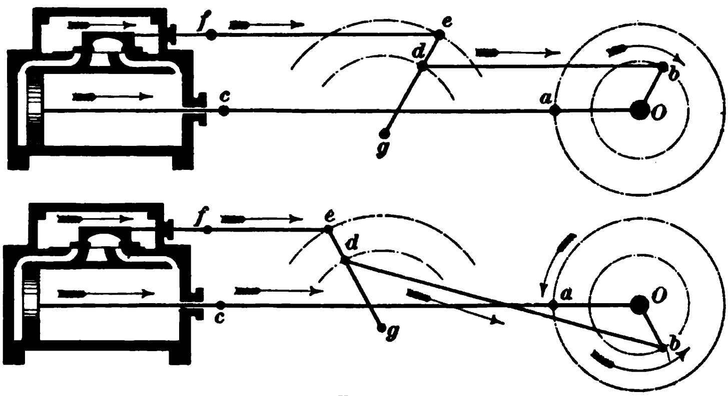


FIG. 276.

lower figure, the valve rod and eccentric-rod move in the same direction. Consequently, by the rule previously given, the eccentric is set 90°+ angle of advance *ahead* of crank.

It is often convenient to pivot the rocker near the center, as shown in Fig. 277. Here, the points *e* and *d*, where the valve and eccentric-rods join the rocker, lie on opposite sides of the pivot *g*. As before, we have the proportion

$$\text{throw of eccentric} : \text{valve travel} :: gd : ge;$$

$$\text{or, throw of eccentric} = \text{valve travel} \times \frac{gd}{ge}.$$

977. It is easily seen, however, that when the rocker is pivoted near the center, as in Fig. 277, the valve rod and eccentric-rod move in opposite directions. Consequently,

to give the valve the proper motion, the eccentric-rod must at all times move in a direction exactly opposite to the direction of the rod attached, as shown in Fig. 276. This can only be accomplished by placing the eccentric exactly opposite the position shown in Fig. 276. That is, instead

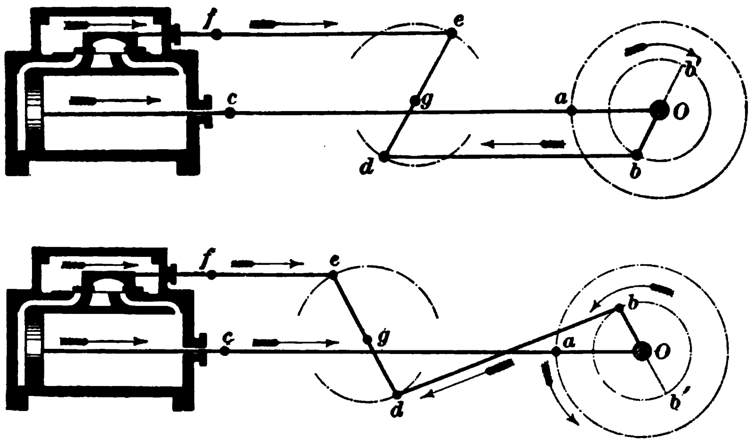


FIG. 277.

of placing the eccentric 90°+ angle of advance *ahead* of the crank, it must be placed 90°− angle of advance *behind* the crank. We have, therefore, the general rule: *In the case of the plain slide valve, if the rocker is so pivoted as to make the valve rod and eccentric-rod move in opposite directions, the eccentric must be placed* **behind** *the crank, and the angle between the two is 90° − angle of advance.*

978. Direct and Indirect Valves.—A slide valve is said to be **direct** when it opens the steam port nearest the crank-shaft by moving in a direction away from the shaft, and closes the steam port by moving towards the shaft. A valve is said to be **indirect** when it opens the steam port nearest the crank-shaft by moving towards the shaft, and closes it by moving away from the shaft.

The plain slide valve already described is a direct valve. It opens the port furthest away from the crank-shaft by

moving towards the shaft, admits steam past the outside edge and exhausts it past the inside edge.

979. An example of an indirect valve is shown in Fig. 278. This valve, which is known as a **piston valve,** consists of two pistons, *a* and *b*, partly hollowed out, and joined by a hollow casting *c*. The valve slides inside a cylindri-

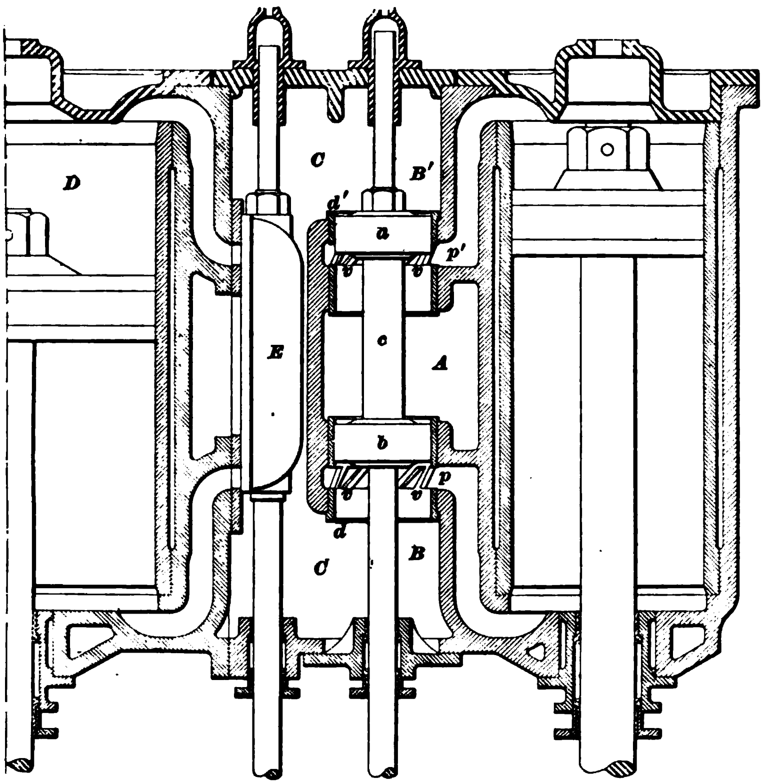


FIG. 278.

cal valve seat. The steam ports *p* and *p'* extend clear around the bushings *d* and *d'* which form the valve seats. Diagonal bars, shown at *v*, *v*, extend across the ports; they act as retaining guides for the packing rings of the valve. These bars are placed diagonally, so that the wear may be

distributed evenly all around the packing rings. The steam is admitted into the central chamber A, and the exhaust steam escapes at the ends B, B'. As shown in the figure, the piston has just made a small part of the downward stroke, and the valve is moving upwards (away from the crank-shaft), and has just opened the steam port p', thus allowing steam to enter past the inside edge of the valve. The valve is, therefore, indirect.

Fig. 278 illustrates a case necessitating the employment of an indirect valve. The chamber C, into which the steam is exhausted, forms the steam chest for a second cylinder D, to which the steam just exhausted past the piston valve is admitted by means of the slide valve E; the steam is permitted to do this through the piston valve moving upwards.

An example of a direct piston valve will be given further on.

980. It is plain that the direction of motion of an indirect valve is exactly opposite that of a direct valve. Hence, as before explained, the eccentric must be set directly opposite the position it would have were a direct valve used. We have, then, the following rule for the position of the eccentric:

When an indirect valve is used, set the eccentric **behind** *the crank, and make the angle between them equal to 90° — the angle of advance. If a rocker is used which makes the valve rod and eccentric-rod move in opposite directions, then set the eccentric* **ahead** *of the crank, and make the angle between them equal to 90° + the angle of advance.* This rule applies whether the engine runs "under" or "over," "right-handed" or "left-handed."

981. The position of the eccentric relative to the crank for both the direct and indirect valves, direct and reversing rocker-arms, is given in the following table. A rocker of the character shown in Fig. 276 will be called a *direct* rocker. One which changes the direction of the motion, as in Fig. 277, will be called a *reversing* rocker:

TABLE 32.

	Kind of Valve.	Kind of Rocker-Arm.	Angle Between Crank and Eccentric.	Position of Eccentric Relative to Crank.
I	Direct ..	Direct.....	90° + angle of advance.....	Ahead of crank.
II ...	Direct ..	Reversing .	90° − angle of advance.....	Behind crank.
III ..	Indirect.	Direct.....	90° − angle of advance.....	Behind crank.
IV...	Indirect.	Reversing .	90° + angle of advance.....	Ahead of crank.

The above table may be applied equally well, whichever direction the engine may run. It is simply necessary to remember that to set the eccentric *ahead* of the crank is to set it so that it reaches a given point in its revolution before the crank reaches the same point in *its* revolution. For example, in Fig. 274, suppose the engine to run under, as shown by the arrow. Then, the eccentric *O b* is set ahead of the crank *O a*, because it will reach the line *O e* before the crank will. If the eccentric were in the position *O b'*, it would be *behind* the crank, because the crank would reach *O e* first. If, however, the engine were "running over," the eccentric, if at *O b* or *O g*, would be behind the crank, but if in corresponding positions, *O b'* or *O f*, it would be ahead of crank.

FORMS OF SLIDE VALVES.

982. Double-Ported Valves.—The plain **D** slide valve, shown in Fig. 263, is largely used on small engines running at moderately slow speeds. When an engine runs very fast, however, the plain **D** valve does not open the port fast enough to allow the steam to follow up the moving piston, and keep up full pressure. To overcome this difficulty, the double-ported valve, Fig. 279, is used. Each port

P has two openings, *C* and *D*. The valve is made with two passages *B*, *B* extending through it; these passages communicate with the steam-chest *A*. In the position shown in the figure, the valve is opening the left steam port. The steam enters the passage *C* past the edge of the valve, and

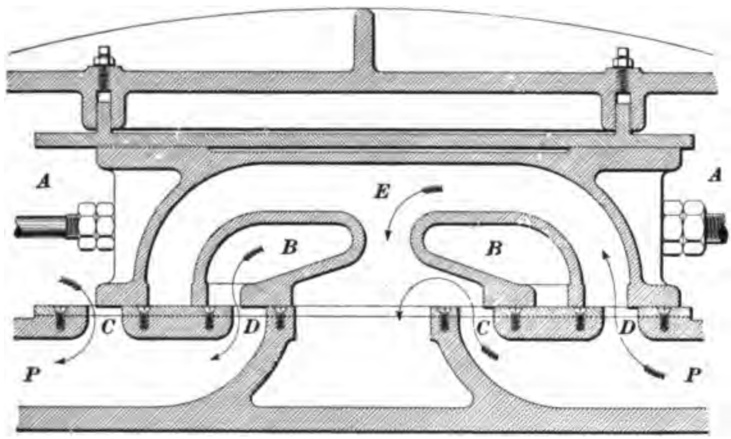


FIG. 279.

enters the passage *D* through the opening in the chamber *B*. In the meantime the exhaust is escaping from the right port into the chamber *E* beneath the valve. It is clear that, with the same travel, the double-ported valve gives double the opening to steam that the plain valve does. Otherwise, the two valves are alike in all respects.

983. The **Allen valve,** shown in Fig. 280, accomplishes the same object. A passage *A* is cast in the valve, and extends clear through it. The shoulders *B*, *B* of the valve seat are so constructed that when the edge *m* of the valve is just even with the edge *l* of the port, the outer edge *p* of the passage *A* is just even with the edge *n* of the shoulder *B* at the other end of the valve seat. Now, when the valve moves a little to the right into the position shown in the figure, steam enters the port directly between the edges *l* and *m*, as in the case of the ordinary valve. At the same time, the edge *p* of the passage has moved past

the edge n of the valve seat; steam thus enters the passage A, and finds there a direct path to the left steam port.

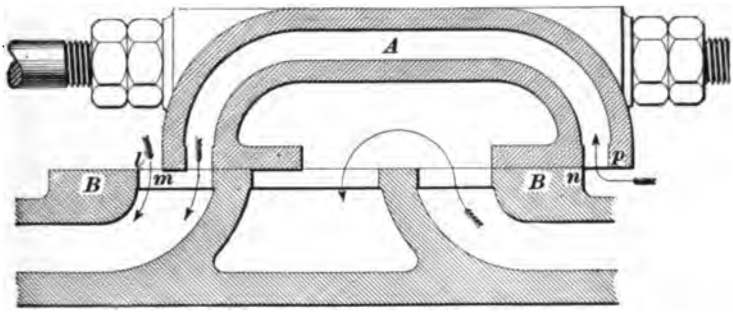


FIG. 280.

984. The **Meyer cut-off valve** is shown in Fig. 281. This valve is used to cut the steam off early in the stroke. With the plain slide valve, the cut-off can not take place much or any before the engine has made half a stroke. If the valve is given enough lap to cause it to cut off early,

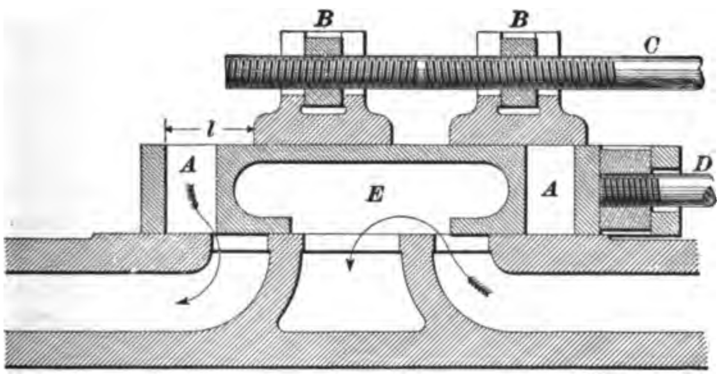


FIG. 281.

compression must necessarily be early also. This is readily seen by examining Figs. 265–272. The Meyer valve consists simply of a flat plate. The steam ports A, A pass through the valve. The lower side of the valve contains the cavity E to receive the exhaust. On top of this main valve slides the cut-off valve, which consists of two plates B, B moved by the valve rod C. The main valve is moved

by the valve rod *D*. The action of the valve may be seen from Fig. 282. Here *O a* represents the crank position as the piston is about to make the forward stroke. The eccentric *O b* of the main valve is set in its usual position, 90° + angle of advance ahead of the crank. The eccentric *O c* is set a little more than 180° ahead of the crank. Now, when the crank moves in the direction shown by the arrows, the eccentric *b* moves to the right and eccentric *c* moves to the left. Hence, the main valve moves to the right, and the cut-off valve *B B* to the left, the distance *l* (Fig. 281), between the left end of the passage *A* and left edge of plate *B* decreasing. When *l* becomes *0*, that is, when plate *B* completely covers passage *A*, the steam is cut off, no matter what the position of the main valve may be. The cut-off valve only affects the cut-off. The compression and release are the same as with the simple **D** valve.

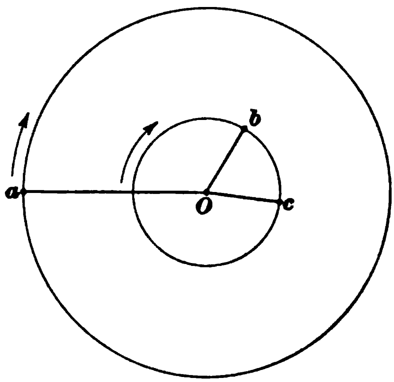


FIG. 282.

The rod *C* has right and left-hand threads on which are screwed the plates *B*, *B*. Hence, by rotating the rod, the plates may be brought closer together or further apart. In the former case, the cut-off is made to take place later; in the latter case earlier. As usually arranged, the rod *C* may be turned by a hand wheel placed outside the steam chest, so that the cut-off may be changed while the engine is running.

DISTURBANCE OF CUT-OFF BY THE CONNECTING-ROD.

985. In Fig. 283 let *a b* represent the path of the center of the wrist-pin, and *c d* the circle described by the center of the crank-pin. Let the diameter of the circle *f g* be equal to the throw of the eccentric. (This is shown

greatly exaggerated.) Assuming the crank to be in the position $O\ c$, that is, on the interior dead center, the length of the line $a\ c$ will represent the length of the connecting-rod. We shall assume that the angle of advance is 20°; further, that the slide valve is set so as not to have any lead. $O\ e$, then, is the position of eccentric when crank-pin is at c. Now, let the crank-pin move in the direction of the arrow x; that is, let the piston commence its forward stroke. Since the valve has no lead, the slightest movement of the crank-pin in the direction of the arrow will cause the valve to open the left steam port. When the eccentric has reached the position $O\ g$, the valve has moved to its

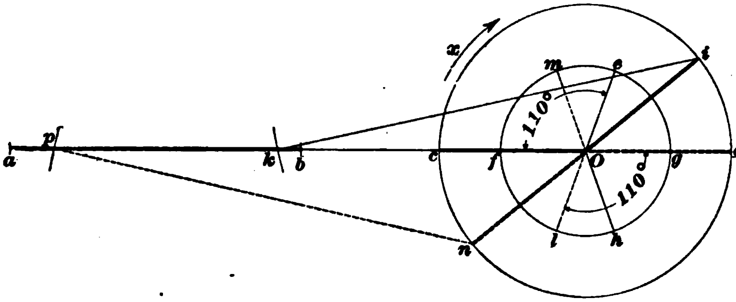


FIG. 283.

furthest position to the right, and any further movement of the crank will cause the valve to begin to close the steam port. To close the steam port fully, the valve will have to move the same distance to the left that it moved to the right to uncover the port. From this it follows that the eccentric has to move through the same angle to close the port that it moved through to open the port. Laying off the angle $g\ O\ h = g\ O\ e$, $O\ h$ will represent the position of the eccentric at the time cut-off takes place. Laying off the angle $h\ O\ i = c\ O\ e$, we find the corresponding crank position. From the point i (the center of the crank-pin) as a center, with a radius equal to the length of the connecting-rod (the length of the line $a\ c$), we describe an arc intersecting the line $a\ b$ at k; the point k will be the position of the center of the wrist-pin at the time of cut-off on

the forward stroke. When the crank passes the exterior dead center, the right steam port will be opened; and at the moment that the crank occupies the position *O d*, the eccentric will be at *O l*; that is, $90° + 20° = 110°$ ahead of the crank. From what has been explained above, it will be clear that cut-off takes place on the return stroke when the eccentric reaches the position *O m*. The corresponding crank position will be *O n*. From *n* as a center, with a radius equal to the length of the connecting-rod, we describe an arc intersecting *a b* at *p*, which gives us the position of the center of the wrist-pin at the time of cut-off on the return stroke.

It will be seen at a glance that cut-off has taken place considerably later on the forward stroke than on the return stroke, since *k b* is less than *a p*. From this we see that a valve having an equal lap and set so as to have an equal lead can not cut off equally on the forward and return stroke. If the valve is set so that the cut-off will be equal, the lead will be unequal.

This is due to the employment of a connecting-rod. As a general rule, it may be stated that the longer the connecting-rod, the less will be the difference in the points of cut-off; and the shorter the connecting-rod, the greater the difference.

The effects of the connecting-rod on the steam distribution of a simple slide valve may be summarized as follows:

It will cause the valve to cut-off and release the steam as well as close the exhaust port later on the forward stroke of the piston than on the return stroke.

VALVE-GEAR PROBLEMS.

986. 1. With the Valve Travel, Lap, and Lead Given, to Find the Cut-Off and Angle of Advance.— With the point *O*, Fig. 284, as a center, and a radius *O A* equal to the length of crank, describe the circle *A C D B*. The drawing should, of course, be made to some convenient scale, say 2, 3, or 4 inches to the foot.

The diameter $A\ B$ represents the stroke of the piston. With O as a center, and with a radius $O\ E$ equal to half the travel of the valve, describe the semicircle $E\ G\ F$. The diameter $E\ F$ represents the valve travel. Suppose that the crank-pin is on the dead center B (see also Fig. 265). Above the line $A\ B$ draw the line $M\ N$ parallel to $A\ B$, ma-

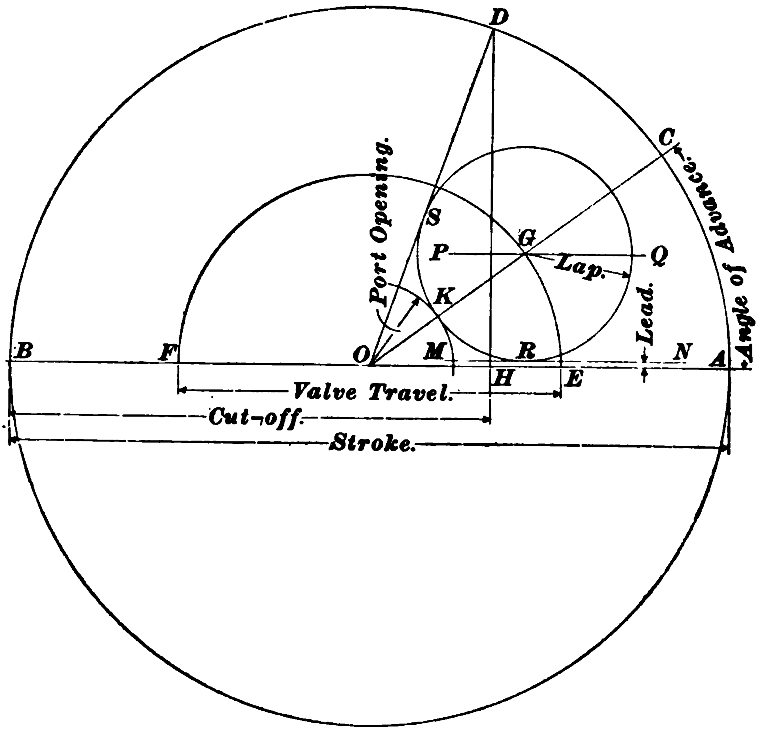


FIG. 284.

king the distance between them equal to the required lead. Also, draw the line $P\ Q$ above and parallel to $M\ N$, making the distance between them equal to the given lap. The line $P\ Q$ intersects circumference $E\ G\ F$ at G. With G as a center, and radius $G\ R$ equal to the lap, describe a circumference; and through O draw the line $O\ D$ tangent to this circumference, touching it at S. Draw also the line $O\ C$ through the center G. From D draw $D\ H$ perpendicular

to $A\ B$. Then, D is the position of the crank-pin when steam is cut off, and $B\ H$ is the distance moved by the piston before cut-off. The apparent cut-off is, therefore, $\frac{B\ H}{B\ A}$. The angle $A\ O\ C$ is the required angle of advance. All dimensions, except the diameter of the crank-pin circle, should be full size.

The student should note in connection with this valve diagram that the angle $B\ O\ C$ is *not* the angular distance the eccentric is ahead of the crank or behind it; the position of the eccentric is not given directly by the valve diagram shown in Fig. 284, but must be found by adding or subtracting the angle of advance to or from 90°, depending upon whether a direct or indirect valve, a direct or reversing rocker is employed.

NOTE.—By *apparent cut-off* is meant the fraction obtained by dividing the distance that the piston has moved at cut-off by the length of the stroke. The term will be more fully explained further on.

987. 2. Given the Valve Travel, Angle of Advance, and Cut-Off, to Find the Lap and Lead.—Draw circumferences $A\ D\ B$ and $E\ G\ F$ as above. Suppose the crank to be in position $O\ D$ when cut-off takes place. Draw $O\ D$, and from A lay off $A\ O\ C =$ angle of advance. Draw $O\ C$ intersecting circumference $E\ G\ F$ in G. Take G as a center, and draw a circumference tangent to $O\ D$. Through the lower point R of this circumference, draw $M\ N$ tangent to circle and parallel to $A\ B$. The distance between $M\ N$ and $A\ B$ is the required lead. The radius $G\ K$ of the circle is the required lap.

In both of the above cases, the distance $O\ K$ between the center O and the circumference $K\ R$ of the lap circle represents the port opening when the valve is at the end of its travel.

Notice that the crank is supposed to be at B or on the left dead center. It is then necessary to lay off the angle of advance from A, the right dead center. In fact, the whole geometrical construction is to the right of the center O.

988. 3. **Given the Lap, Lead, and Point of Cut-Off, to find the Valve Travel and Angle of Advance.**—(See Fig. 284.) Draw the line *O D*, as in Problem 2, and the line *M N*, as in Problem 1. Open the compass to the required lap and find by trial a center *G*, from which a circle may be described tangent to the lines *O D* and *M N*. With *O G* as a radius and *O* as a center, describe the circle *E G F*, passing through *G*. Then, *E F* is the required valve travel. Through *G* draw the line *O C*. Then, angle *A O C* is the required angle of advance.

989. 4. **Given the Cut-Off, the Lead, and the Opening of the Port When the Valve is at the End of its Travel, to Find the Lap, Travel, and Angle of Advance.**—(See Fig. 284.) At cut-off the crank-pin is at *D*. As in Problem 3, draw the lines *O D* and *M N*. With *O* as a center and radius *O K* equal to the given port opening, describe an arc of a circle. Now, by trial find a center *G* from which a circle may be described, which shall be tangent to this arc just drawn, and also tangent to each of the lines *O D* and *M N*. This circle is *R K S*, the points of tangency being *R*, *K*, and *S*. The radius *G K* is the required lap. Through *G* draw the line *O C*, and the angle *A O C* will be the required angle of advance. Through *G* draw the semicircle *E G F*. Then, *E F* is the valve travel required.

CLEARANCE: REAL AND APPARENT CUT-OFF.

990. Clearance.—When the crank is on a dead center, and the piston at the end of its stroke, there is always a space between the piston and the cylinder head. The volume of this space plus the volume of the one *steam* port leading into it is called the **clearance.** Thus, in Fig. 273, the piston is at the end of its return stroke, and the clearance is the volume of the space between the piston and the left cylinder head plus the volume of the left steam port. In other words, the clearance may be defined as the volume of steam between the valve and the piston when the latter

is at the end of the stroke. The clearance of an engine may be found by putting the engine on a dead center and pouring in water until the space between the piston and the cylinder head, and the steam port leading into it, are filled. The volume of the water poured in is the clearance.

The clearance may be expressed in cubic feet or cubic inches, but it is more convenient to express it as a percentage of the volume swept through by the piston. For example, suppose the clearance volume of a 12″ × 18″ engine is found to be 128 cubic inches. The volume swept through by the piston per stroke is $12^2 \times .7854 \times 18 = 2{,}035.8$ cu. in. Then, the clearance is $\frac{128}{2{,}035.8} = .063 = 6.3\%$. The clearance may be as low as $\frac{1}{2}\%$ in Corliss engines, and as high as 14% in very high speed engines.

991. Theoretically, it would be better if there were no clearance, since the steam which fills the clearance space does no work except during expansion; it is exhausted from the cylinder during the return stroke, and represents so much dead loss. This is remedied, to some extent, by compression. If the compression were carried up to the boiler pressure, there would be very little, if any, loss, since the steam would then fill the entire clearance space at boiler pressure, and the amount of fresh steam needed would be the volume displaced by the piston up to the point of cut-off, the same as if there were no clearance. It is not practicable, however, to run an engine without any clearance, owing to the formation of water in the cylinder due to the condensation of steam, particularly when starting the engine. As water is practically incompressible, some part of the engine would be broken when the piston reached the end of its stroke, provided there were no clearance space for the water to collect in; usually, the cylinder heads would be blown off. Neither is it always advisable to compress to boiler pressure, as that is liable to strain parts of the engine too severely. As a general rule, the compression should be such that the engine will pass over the top and bottom centers without

knocking, and just what amount of compression is needed to accomplish this must be found by trial.

Another reason for having clearance is to allow for alterations in the length of the connecting-rods when the brasses are let together. As marine rods are generally designed, the effect of taking up the wear of both ends is to shorten the rod, and thus endanger the bottom cylinder head; this is still further rendered necessary by the wear of the main bearings. So it is seen that we require much more clearance at the bottom than at the top end of cylinder.

992. Real and Apparent Cut-Off: Ratio of Expansion.—It is customary in speaking of the point of cut off to say that the engine cuts off at $\frac{1}{2}$ stroke, $\frac{1}{4}$ stroke, etc. By this is meant that the steam is cut off when the piston has completed $\frac{1}{2}$ or $\frac{1}{4}$ of its stroke, as the case may be. For example, if the stroke is 48 inches, and the steam is shut off from the cylinder when the piston has moved 18 inches, the cut-off is $\frac{18}{48} = \frac{3}{8}$. The cut-off thus spoken of is the **apparent cut-off.**

993. The **real cut-off** takes account of the clearance space. It is the ratio between the volume of steam in the cylinder and clearance space when the piston is at the point of cut-off and the volume of steam in cylinder and clearance space when the piston is at the end of the stroke. For example, let the volume of steam between the valve and piston when the latter is at cut-off be 4 cubic feet. Suppose that when the piston is at the end of its stroke the volume of steam in the cylinder and clearance space is 9 cu. ft. Then, the real cut-off is $\frac{4}{9}$.

994. The relation between the apparent and real cut-offs may be shown graphically as follows: Let the length $A B$,

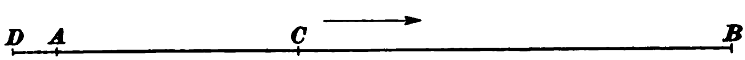


Fig. 285.

Fig. 285, represent the stroke of the engine. Suppose that the piston is moving in the direction of the arrow, and that

the steam is cut off when the piston has reached the point C. Then, according to the above, the apparent cut-off is $\frac{AC}{AB}$. It is clear that, since AB represents the stroke of the piston, it will also represent to some scale the volume swept through by the piston. Now, to the same scale, lay off AD equal to the volume of the clearance. Then, from the above definition, the real cut-off is $\frac{DC}{DB} = \frac{AC + AD}{AB + AD}$.

Let s represent the apparent cut-off; k, the real cut-off, and i, the clearance expressed as a per cent. of the stroke. Then, in Fig. 285, $s = \frac{AC}{AB}$, $i = \frac{AD}{AB}$, and $k = \frac{DC}{DB}$.

Rule 170.—*To find the real cut-off, add the clearance expressed as a per cent. of the stroke to the apparent cut-off, and divide the sum by one plus the clearance.*

That is, $$k = \frac{s + i}{1 + i}.$$

EXAMPLE.—In a 13" × 18" engine the steam is cut off when the piston has moved over 8 inches of its stroke. The clearance is 8% of the volume displaced by the piston. Find the apparent cut-off and real cut-off.

SOLUTION.—Apparent cut-off is $\frac{8}{18} = \frac{4}{9} = .444 = 44.4\%$. Ans.

From rule **170**, the real cut-off is

$$k = \frac{s + i}{1 + i} = \frac{.444 + .08}{1 + .08} = \frac{.524}{1.08} = .485 = 48.5\%. \text{ Ans.}$$

995. The **ratio of expansion,** also called the **number of expansions,** is the ratio between the volume of steam in cylinder and clearance space when the piston is at the end of its stroke, and the volume in the cylinder and clearance space when the piston is at the point of cut-off. That is, in Fig. 285, the ratio of expansion is $\frac{DB}{DC}$. Since $\frac{DB}{DC} = \frac{1}{\frac{DC}{DB}} = \frac{1}{k}$, it follows that the ratio of expansion is the

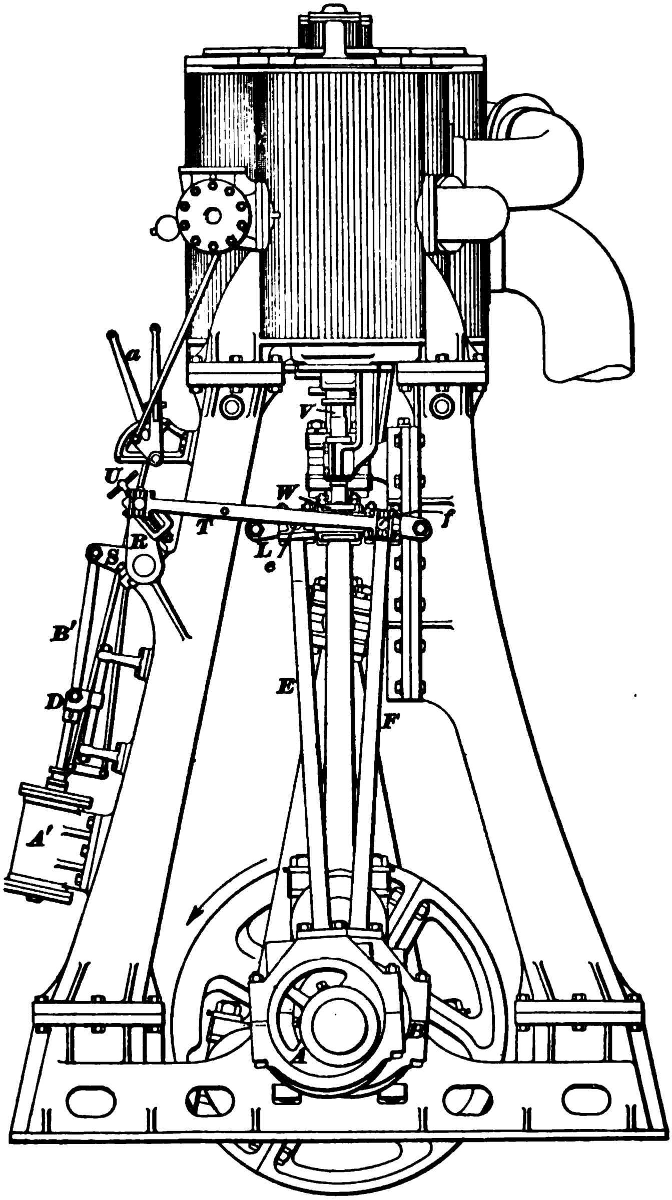


FIG. 293.

single eccentric; the eccentric *B* will govern the steam distribution, the eccentric *A* affecting it but very little. Consequently, the engine will run in the direction of the arrow.

Now, let the link be moved until the eccentric-rod *E* is in line with the valve stem. The eccentric *A* will then impart motion to the valve. The valve in this case being an indirect one, the eccentric must be behind the crank, and the latter will move in the direction opposite to that shown by the arrow.

When the engines are driving the vessel ahead, the link being in full gear, it is said to be in **full gear ahead,** and the eccentric governing the steam distribution is named the **go-ahead** eccentric. With the engines driving the vessel astern, the link is in **full gear astern,** and the eccentric governing the steam distribution is the **go-astern** eccentric.

1034. Besides reversing the direction of the motion, the link performs another important duty. When the link is placed in *mid-gear;* that is, when the block *W* is exactly in the center of the link *L*, the valve rod *V* is acted on equally by the eccentrics *A* and *B*. Hence, the engine will run in neither direction. Suppose, now, the link is moved to the right until the block is in some intermediate position, say one-fourth of the distance between *e* and *f*. Then, the valve rod will be actuated chiefly by eccentric *A*, but will also to some extent be affected by the motion of eccentric *B*. The result will be that the valve rod will travel a shorter distance than it would if actuated by eccentric *A* alone. The cut-off will take place earlier and the compression will be greater. Hence, the link may be used to regulate the amount of work done in the cylinder.

In order to allow the cut-offs of an engine having two or more cylinders and cranks to be adjusted independently of each other, the reversing rocker *R* is slotted at the end. The reach rod *T* is attached to a movable block which is closely fitted into the slot. By means of the screw *U* it may be readily moved to the right or left, thus moving the link either towards mid-gear or full gear ahead without affecting

the other links. To prevent any motion of the block while the engine is running, a check nut which clamps it to the slotted end of the reversing rocker is fitted to it.

1035. As shown in Fig. 293, the eccentric-rods *E* and *F* are **open**; in some cases the rods are **crossed.** When the rods are open, the lead of the valve increases as the block is made to approach the center of the link. When the rods are crossed the lead becomes less as the block nears **mid-gear.** Most marine engines are fitted with open rods.

In small engines the link is moved by means of a lever, as *W*, Fig. 260. The reach rod *X* is attached to the lever and link. To hold the lever in position, a notched quadrant *Q* is provided, a latch fitting into the notches, being raised or lowered by means of the latch handle shown at the top of *W*. On large engines, however, owing to the weight and friction of the link motion and valves, the reversing has to be done by steam or other power. In Fig. 293, *A'* is a steam cylinder fitted with a piston, piston rod, and a cross-head *D*. A connecting-rod *B'* is attached to the latter, and also to the crank arm *S*, which is keyed to the same shaft as the reversing rocker *R*. By a small valve operated by a lever *a*, situated within easy reach of the engineer, steam may be admitted to either side of the piston, thus pushing it either upwards or downwards, and, by means of the connecting mechanism, moving the link in the corresponding direction.

1036. The ideal valve gear should instantaneously open the steam port wide, keep it wide open during the period of admission, and close it instantaneously at the time of cut-off, thus preventing any wire-drawing of the steam. It should also open the exhaust port promptly, keep it wide open during exhaust, and close it promptly. The link motion, however, will not do this, which is a defect inseparable from its mechanism. Of late years designers have perfected valve gears closely approaching the conditions set forth above, and, of the many in existence, the two most generally employed in marine work are described below.

THE JOY VALVE GEAR.

1037. In Fig. 294 the **Joy** valve gear is shown. In this, which belongs to the class known as **radial** valve gears, no eccentric is used, but motion is imparted to the valve by the motion of the connecting-rod A. A link B is pivoted to the connecting-rod at a; its other end is pivoted at b to the swinging lever C, which is fulcrumed at c. At the point d on the link B, the lever D is attached, which is free to turn about the fulcrum e at the end of the reversing lever E. This lever E is free to turn about f, f being a pin carried by the reversing rocker shown directly behind the reversing lever E. This reversing rocker remains stationary for any running position of the gear, but may by suitable means be turned about a fulcrum fixed to the column. With the gear in the position shown, this fulcrum lies directly back of e. At g the valve-stem connecting-rod G is attached. When the engine is in motion the center of the pin a will describe the closed curve $a\ a'$; the center of the pin d the curve $d\ d'$; the lever C will oscillate in the arc $b\ b'$, and with the reversing lever occupying the position $e\ f$, g will describe the curve $g\ g'$. Assume the crank to be on the top center, as shown in the figure. Then the slide valve, which is assumed to be a direct valve, will have opened the upper steam port an amount equal to the lead. If the crank revolves in the direction of the arrow x, the point g moves in the direction of the arrow z', and the valve continues to open the steam port until g reaches the lowest point of the curve $g\ i\ g'$. After passing the lowest point, the valve moves upwards, thus closing the steam port. Shortly before the engine reaches the bottom center, i. e., shortly before g occupies the position i, the exhaust port is opened, and remains open until g reaches the highest point g'. After passing this point the exhaust port closes quite rapidly, and closes entirely before the crank reaches the top center again. The engine is reversed by shifting the fulcrum f of the reversing lever until it occupies the position f'. The point g will now describe the curve $g\ i\ g''$. Assuming the crank to be on the top center, the upper steam port must be

opened. Now, since the lowest point of the curve $g\,i\,g''$ is to the right of g, it follows that in order that the valve may

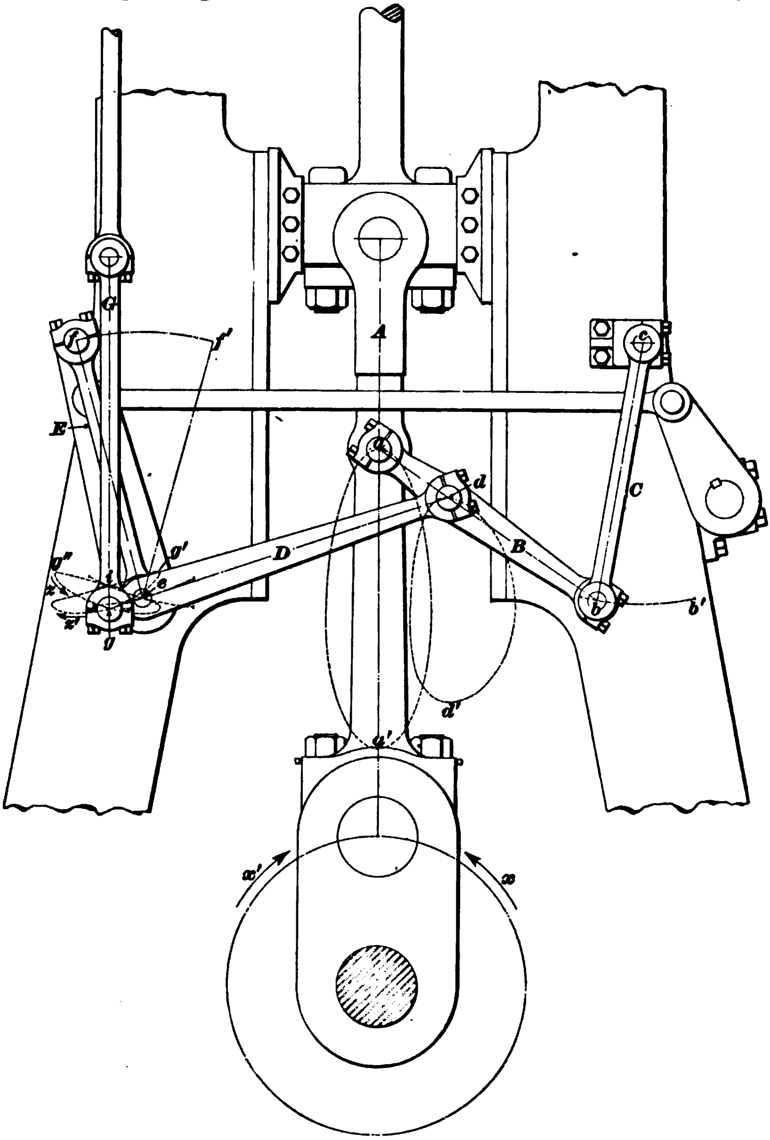


FIG 294.

open the steam port, g must move in the direction of the arrow z; but this can not take place unless the crank revolves in the direction of the arrow x'; that is, in a direction opposite to that in which it revolved when the fulcrum of the reversing lever was at f. The mid-gear position occurs when f occupies a position just midway between f and f'. If f occupies any intermediate position, the cut-off will take place earlier. This gear will give a very early cut-off without unduly increasing the lead and the compression, differing in this respect from the link motion, in which, as the cut-off occurs earlier, the lead and compression become greater.

THE SEE-MARSHALL VALVE GEAR.

1038. The **See-Marshall** radial valve gear is shown in Fig. 295. In this only one eccentric, shown at A, is used. It is placed on the shaft so that its center coincides with the center line of the crank. The eccentric-rod B is pivoted at a to the radius rod C, which may turn on the fulcrum c. At the free end b of the eccentric-rod, the valve-stem connecting-rod D is attached. Assuming the crank to be on the top center, as in the figure, and the crank to be revolving in the direction of the arrow x, the point b will describe the closed curve $b\ d\ e\ f$, supposing the radius rod to occupy the position $a\ c$. With the crank on the upper dead center, the upper steam port is just uncovered, and the slide valve opens until the lowest point d of the curve is reached. After passing this point the valve closes, the cut-off depending on the amount of lap. When the crank is on the bottom center, the point b is at e, the lower steam port is uncovered, and remains open until b reaches the highest point f of the curve, when the valve commences to close. Now, the vertical distance g represents the distance the lower steam port is opened, and h the opening of the upper steam port. A glance at the figure shows g to be greater than h. This involves a later cut-off on the up stroke than on the down stroke—the very thing desired in vertical engines, as the greater power should be developed on the up stroke in order to counterbalance the

weight of the piston, piston rod, cross-head, and connecting-rod. When an indirect valve and a reversing rocker-arm is employed, the eccentric will have the same position as is shown in Fig. 295, which is also the correct position for a

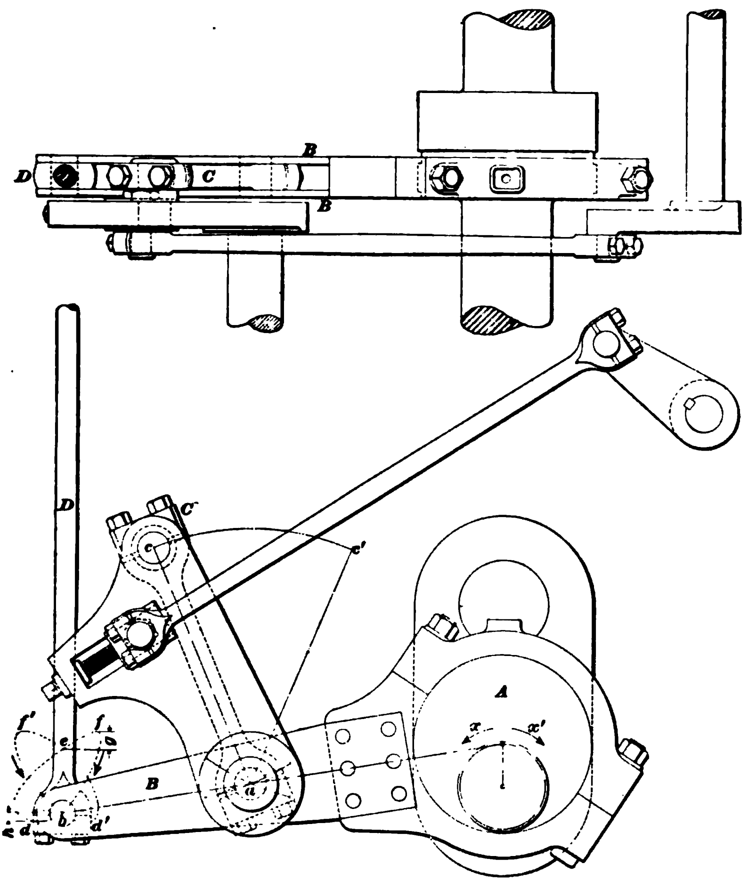


Fig. 295.

direct-connected direct valve. When a direct-connected indirect valve is used, and also when a direct valve and reversing rocker-arm is employed, the eccentric position will be 180° from that occupied in the figure.

The direction in which the engine runs may be reversed by changing the fulcrum c to c'. The crank will now revolve in the direction of the arrow x', and b will describe the curve $b\,d'\,e\,f'$. The cut-off may be readily changed by placing the fulcrum c in any intermediate position, c and c' being its extreme positions for full gear ahead and full gear astern, respectively. The nearer c is moved to a point midway between c and c' the less the valve travel will be, and the sooner will the cut-off take place. Conversely, the nearer the fulcrum is to c or c' the larger the valve travel and the later the cut-off. In the See-Marshall gear the lead is constant for all cut-offs.

SETTING THE SLIDE VALVE.

1039. Dead Centers.—Referring to Fig. 258, it is plain that when the piston P is at the end of its stroke at the end h of the cylinder, the crank-pin A must lie at the point m in the crank-pin circle. In this position, the crank $O\,A$ and connecting-rod $A\,B$ lie in the same straight line. Likewise, when the piston is at the other end of the stroke, the pin A lies at the point n, and the crank and connecting-rods are again in the same straight line.

When the crank occupies either of these positions, the engine is said to be on its **dead center.** All the pressure of the steam on the piston is transmitted directly to the shaft O, because the reciprocating parts are in a straight line. Consequently, there is no tendency to turn the crank, and the engine can not be started until turned off from the dead center. When the crank occupies the position $O\,m$, it is said to be on its **interior** dead center, and when it occupies the position $O\,n$, on its **exterior** dead center.

In the case of a vertical engine with a cylinder above the crank-shaft, when the crank occupies the position $O\,m$, it is said to be on the **top** dead center, and when it occupies the position $O\,n$, on the **bottom** dead center.

1040. To Place the Engine on its Dead Center.—It is sometimes necessary to place the engine exactly on its

center in order to set the valve. A common method of doing this is shown in Fig. 296. When the cross-head is very near the end of its travel, make a mark *b* on one of the guides, slightly above the upper edge of the cross-head. Now, turn the engine in the direction of arrow *x* until the upper edge of the cross-head comes even with the mark *b*. While the engine is in this position, take a tram *d*, both ends of which are pointed, and place one end in a center punch mark made in some convenient part of the frame, of the column say, as shown in Fig. 296. With the other end of the tram make a mark *e* on the face of the crank (for convenience the mark is shown on the side of the crank in the illustration). The engine will probably not be exactly on the center; the crank-pin will be say in a position slightly to the left of the center. Now turn the engine in the direction of the arrow *x* until the edge of the cross-head again comes even with the mark *b*. The crank-pin will now be the same distance to the right of the center as it was to the left in the first place. It is evident that the marking point of the tram will not be opposite the mark *e* now, but will make a new mark *e'* on the face of the crank. Now, make a mark *f* half way between the marks *e* and *e'*, and turn the engine until the mark *f* comes opposite the point of the tram. The engine is then exactly on its dead center.

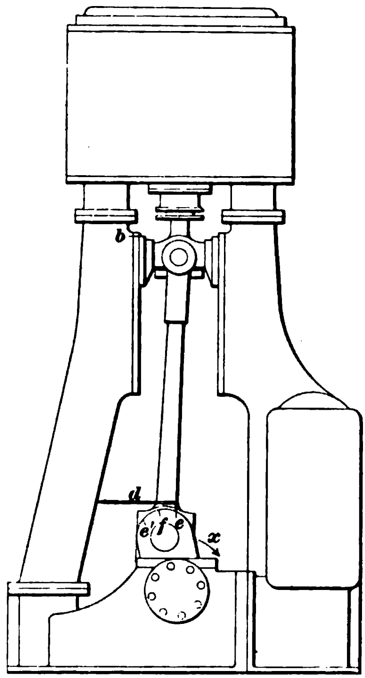


FIG. 296.

In a similar manner the engine may be placed on the bottom center.

To insure accuracy, the tram should be of such length that the marking point will be approximately in a plane passing through the axes of the crank-shaft and cylinder. In some cases it is more convenient to make the marks *e* and *e'* on the jacking wheel, or, in case of a paddle-wheel engine, on the paddle wheel. In such cases the tram may be of any convenient length.

NOTE.—A jacking wheel is a wheel placed on the shaft of a screw-propeller engine, by means of which the engine may be turned around by hand.

1041. Setting the Slide Valve.—Setting a slide valve is really a very simple operation, and more a matter of reasoning than of rule. If the Stephenson link motion is used, the usual procedure is as follows: The link is thrown in full gear ahead and the crank placed on the top dead center. Next, the go-ahead and the go-astern eccentrics are turned around on the shaft until they have about the proper angular advance as near as can be judged by eye. Then the valve stem is lengthened or shortened until the upper steam edge of the valve is just about to uncover the upper steam port. The crank may now be placed on the bottom dead center. The distance the lower steam port is opened, or the distance the lower steam edge of the valve has traveled below the lower edge of the lower steam port, is measured. In the first case considered, the valve should be lowered one-half the distance the port is opened; in the second case the valve should be raised one-half the distance the valve has traveled past the lower steam port. The valve is now adjusted so that it will travel equally both ways from its mid-position. Next, the go-ahead eccentric is shifted until the desired lead is obtained, which will be equal at top and bottom.

But most vertical inverted engines need a greater lead on the bottom than on the top, the common practice being to make the bottom lead twice as great as the top lead.

The valve may first be set for an equal lead in the manner described above; the amount of lead may then be made equal to one-half the sum of the two leads it has been

decided to use. For instance, having decided to use a lead of $\frac{1}{4}$ inch on top and $\frac{1}{2}$ inch on the bottom, the valve should be set first for an equal lead of $\frac{\frac{1}{4}+\frac{1}{2}}{2} = \frac{3}{8}$ inch. Next, the valve should be raised one-half the difference of the two leads; that is, $\frac{\frac{1}{2}-\frac{1}{4}}{2} = \frac{1}{8}$ inch, when the valve will be set correctly for the forward motion. To set it for the backing motion, the link is thrown in full gear astern, the crank placed successively on the top and bottom centers, and the top and bottom leads measured. If the sum of the two leads for the backing motion is equal to the sum of the two leads for the forward motion, the eccentric has the proper angular advance. If the sums of the leads do not agree, the go-astern eccentric is shifted until they do. Having placed the eccentric in its proper position, the crank is placed on the top center, and the top lead is measured. Should it be found to be less than that obtained in the forward motion, the eccentric-rod of the go-astern eccentric must be shortened an amount equal to the difference of the two leads for the two motions. Should the top lead be found to exceed that of the forward motion, the go-astern eccentric-rod must be lengthened an amount equal to the difference of the two leads for the two motions. This may be done by placing a liner of the required thickness under the foot of the eccentric-rod. Having done this, the valve will be set correctly for the two motions.

In setting the valves of an engine fitted with link motion, it should be remembered that moving the eccentric only changes the amount of lead, while moving the valve on the stem serves to make it travel equally in both directions from its mid-position.

In some instances the valve can not be moved on the valve stem. In that case all adjustments for equal travel, etc., must be made by placing liners under the foot of the eccentric-rod, or removing liners therefrom.

1042. To Set the Valve with a Joy or See-Marshall Valve Gear.—Put the engine in full gear ahead

and place the crank on the top center. Raise or lower the valve until the upper steam port is just about to be uncovered. Place the crank on the bottom center and measure the amount of lead. Then, if it is desired to have the leads equal, lower the valve one-half the amount of the bottom lead. If the top lead is to be less than the bottom lead, lower the valve an amount equal to the required top lead. The sum of the two leads can not be changed very readily in either the Joy or the See-Marshall valve gears.

STEAM ENGINES.

(PART 2.)

STEAM MEASUREMENTS.

THE INDICATOR.

1043. The arrangement described in connection with Figs. 265 to 272, Arts. **963** to **970,** for recording the steam pressure at all points of the stroke of the piston, would be impossible to put into actual operation; besides, the diagram traced by the pencil would be altogether too large to be handled conveniently. To overcome these objections, an instrument called the **indicator** is used. The principal reason for obtaining a diagram of this kind is that it affords ready means of computing the mean pressure of the steam upon the piston during one stroke. If the mean pressure on both sides of the piston, the length of the stroke, and the number of strokes per minute are known, the horsepower of the engine can be easily found.

1044. Fig. 297 shows the general appearance of an indicator, and Fig. 298 shows one in section. The instrument consists essentially of a cylinder containing the piston *g* and the spiral spring *a*. From this cylinder projects an arm *h*, which carries the cylindrical drum *f*. By turning a cock connected to the small pipe to which the indicator is attached, steam may be admitted to, or shut off from, the cylinder of the indicator at pleasure. When steam is admitted through the channel *s*, Fig. 298, its pressure causes the piston *g* to rise. The spiral spring *a* is compressed, and resists the upward movement of the piston. The height to which the piston rises should then be in exact proportion to the

pressure of the steam, and as the steam pressure rises and falls, the piston must rise and fall accordingly.

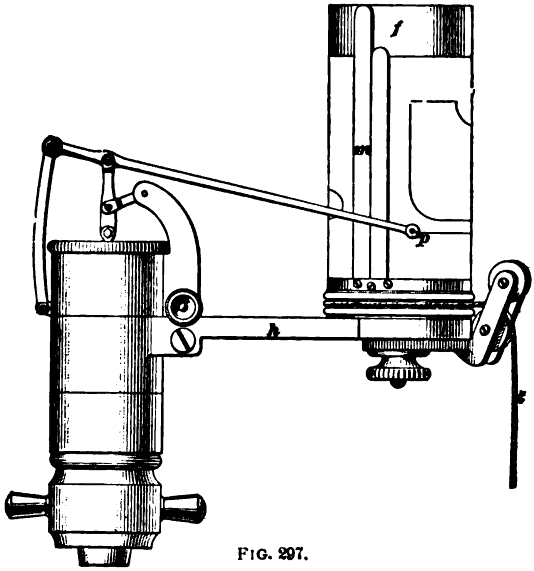


FIG. 297.

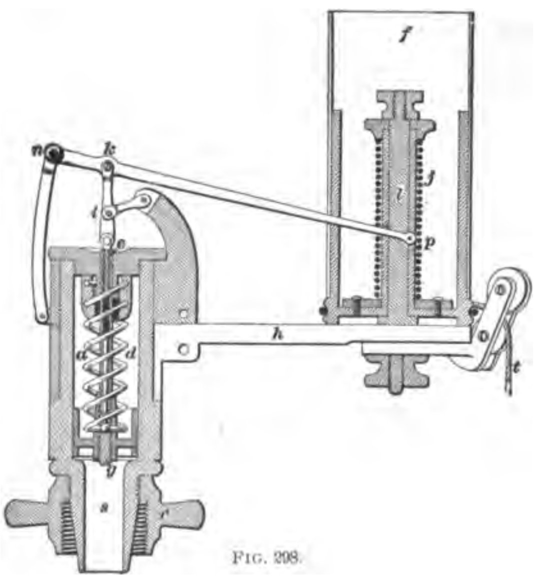


FIG. 298.

To register this pressure, a pencil might simply be attached to the end of the piston rod *e*, the point of the pencil being made to press against a piece of paper. It is desirable, however, to restrict the maximum travel of the piston to about half an inch, while the height of the diagram may advantageously be two inches or more. To obtain a long range of the pencil, combined with a short travel of the piston, the pencil is attached at *p* to the long end of the lever *n k p*. The fulcrum of the lever is at *n*. The piston rod is connected to the lever at *k* by means of the link *i*. The pencil motion is thus $\frac{np}{nk}$ times the piston travel. This ratio $\frac{np}{nk}$ is, for most indicators, either 4, 5, or 6. The point *p* is forced to move in a vertical straight line by the arrangement of links and joints *i*, *e*, *n*, and *k*.

1045. The height to which the piston will rise under a given steam pressure depends upon the stiffness of the spring. Indicators are usually furnished with a number of springs of varying degrees of stiffness, which are distinguished by the numbers 20, 30, 40, etc.

These numbers indicate the pressure per square inch required to raise the pencil at *p* one inch. Thus, if a 40 spring is used, a pressure of 40 pounds per square inch raises the pencil one inch, and the vertical scale of the diagram is, therefore, 40 pounds per inch. That is, the vertical distance in inches of any point on the diagram from the atmospheric line multiplied by 40 gives the gauge pressure per square inch at that point. The scale of the spring chosen should not be less than half the boiler pressure. For example, we should choose a 40 spring for a steam pressure of 75 pounds per square inch, and so on.

1046. The indicator, however, must not merely register pressures, but it must register them in relation to the position of the piston. To accomplish this object, the drum *f* is provided. This drum can be revolved on its axis by pulling the cord *t*, which is coiled around the drum. When the pull is released, the spring *j* rotates the drum back to

its original position. If now the cord *t* be attached to some part of the engine which has a motion proportional to the motion of the piston, the motion of the drum will also be proportional to the motion of the piston.

To attach the indicator to the engine, a hole is drilled in

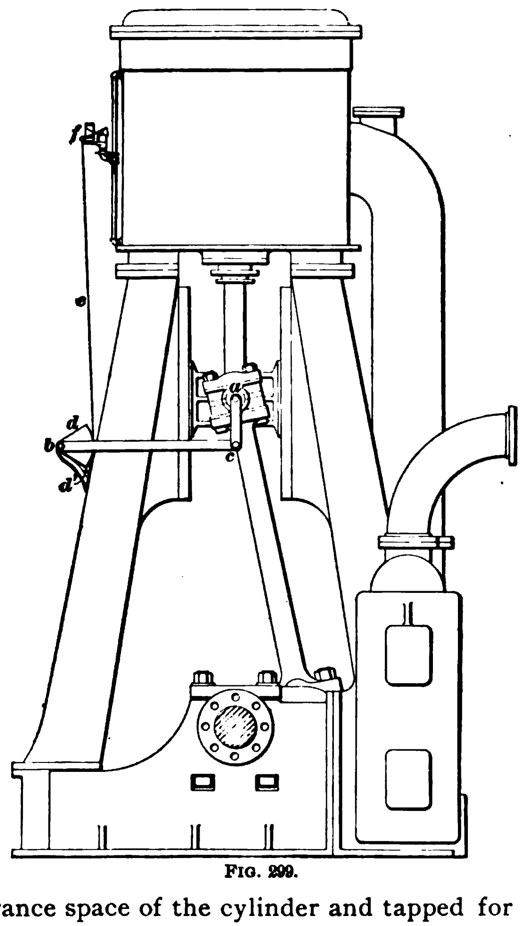


FIG. 299.

the clearance space of the cylinder and tapped for a ½-inch nipple. The nipple has an elbow, into which is screwed the indicator cock. The indicator is then attached directly to the cock by the nut *r*, the conical projection *s* of the indicator wedging tightly into the cock to prevent the leakage

of steam. It is preferable to have an indicator at each end of the cylinder, but if that is not convenient, one indicator may be connected with both ends of the cylinder by means of a three-way cock, as shown in Fig. 299.

1047. Reducing Motion.—The motion of the drum is nearly always taken from the cross-head. Since, however, the stroke of the cross-head is longer than the circumference of the drum, it is necessary to arrange a form of mechanism, some point of which will copy, on a reduced scale, the stroke of the piston. Such a mechanism is called a **reducing motion.**

A common form of reducing motion is shown in Fig. 299. In this a link *a c* is pivoted to the cross-head and to the reducing lever *b c*. As usually arranged, *b c* is keyed to a small shaft *b* carried in brackets bolted to the columns, as shown in the figure. A sector *d*, or, as it is usually called, a **brumbo pulley,** is keyed to the same shaft; its periphery is grooved to receive the indicator cord *e*, which may be fastened to a small screw, screwed into *d* at *d'*. The indicator is shown at *f*.

Let $r =$ the radius of brumbo pulley, and
$m =$ the length of the lever bc. Then,

$$\frac{\text{length of diagram}}{\text{length of stroke}} = \frac{r}{m}, \text{ or } r = \frac{\text{length of diagram} \times m}{\text{length of stroke}}.$$

Therefore, to find the radius of the pulley, multiply the required length of the diagram by the length of the lever, and divide the product by the length of the stroke, all dimensions being taken in inches.

The length of the link *a c* may be made about one-third of the stroke; *b c* may be of any convenient length, but *b* should be so located that when *a* is in its mid-position, that is, at mid-stroke, *a c* will be parallel to the line of motion of the cross-head, and *b c* perpendicular to it.

With this arrangement, the diagrams taken are practically correct, in so far that the points on the length of the diagram correspond to the different points of the stroke; for the ratio *b d* : *b c* is the same for all positions.

1048. Another reducing motion is the **slotted swinging lever,** shown in Fig. 300. A pin *W* in the cross-head moves in a slot in one end of the lever, which is pivoted at *U* to some convenient point. The indicator cord is attached at *V*. The length of the line *A B* represents the stroke of the engine. With this arrangement, the length *U W* is constantly changing while the length *U V* remains constant, as will be seen by comparing the lengths of the lever arms shown in full and dotted lines respectively; hence, the slotted swinging lever can not give an exact representation

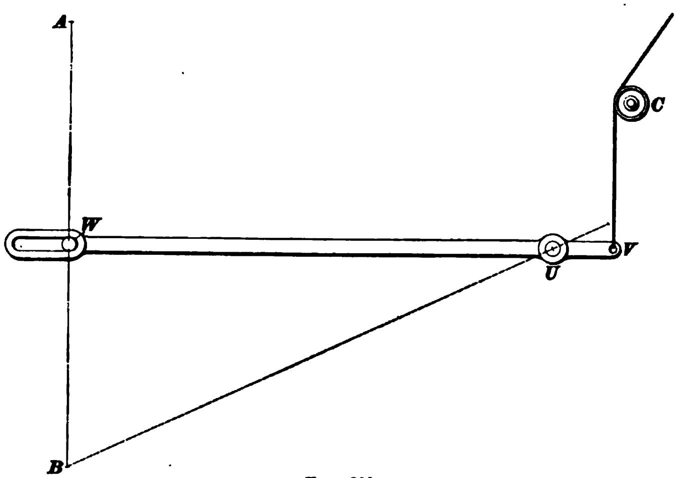


FIG. 300.

of the piston travel on a reduced scale; i. e., it will distort the diagram. The length of *U V* may be found by the rule given above, using the dimension *U V* for *r* and *U W* for *m*.

To obtain the best results possible with this arrangement, *W U* should be perpendicular to the line of motion of the cross-head when *W* is in its mid-position (that is at mid-stroke), and at the same time the indicator cord should be perpendicular to *U V*. If necessary, a small guide pulley *C* may be employed to give the proper direction to the cord. The part of the cord beyond the guide pulley may then run in any required direction.

EXAMPLE.—The desired length of the diagram is 3.5 inches; the length bc, Fig. 299, is 36 inches, and the stroke is 30 inches. What should be the radius of the brumbo pulley?

SOLUTION.—Applying the rule given in Art. **1047**, we have radius of pulley $= \frac{3.5 \times 36}{30} = 4.2$ in. Ans.

EXAMPLE.—The length UW, Fig. 300, being 36 inches; stroke, 30 inches, and desired length of diagram, 4 inches, what should be the length of UV?

SOLUTION.—This may be solved in the same manner as the preceding example, that is,

$$UV = \frac{4 \times 36}{30} = 4.8 \text{ in. Ans.}$$

1049. For convenience, the cord should be in two parts; one attached to the reducing motion, and one to the indicator. The end of one part is looped; the end of the other has a hook attached to it.

A convenient arrangement is shown in Fig. 301. The hook a is attached to the indicator cord. The cord e from the reducing motion is passed through a wooden or metal plate b, and fastened at c as shown. By slackening the cord

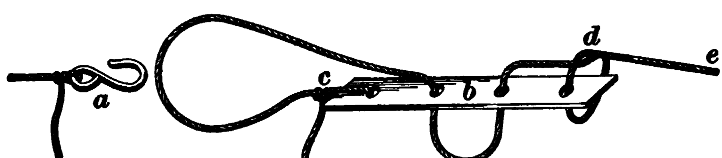


FIG. 301.

at the point d, the plate may be slipped to any position along the cord. The length is thus easily adjusted.

When the indicator is in operation, the hook is hooked into the loop. By unhooking the two cords, the indicator may be stopped to put on a card, without stopping the engine.

The stretching of the indicator cord may introduce serious errors in the diagram. Hence, it is better, if possible, to use a wire instead. If a cord is used, it should be as short as convenient. It should also be throughly stretched before being used.

INDICATOR DIAGRAMS.

1050. Directions for Taking Indicator Diagrams.—Before attaching the indicator to the engine, see that it is clean and in good working order. The piston should move freely. See that the joints of the various levers and links are oiled with fine oil, and that they are slack enough to avoid friction, yet not so slack as to allow the pencil to shake. Adjust the pencil so that it just touches the paper, and sharpen the point so that it makes a very fine light line. A heavy coarse line on a diagram is a sign of poor work.

Select a spring which will give a diagram about 1½ or 1¾ inches in height. If upon trial, the spring chosen makes a wavy line, choose a stiffer one. A stiffer spring is required on a fast-running engine than on a slow engine, even when the steam pressure is the same. See that there is no backlash between the piston and spring.

Adjust the length of the cord so that the drum turns backwards and forwards without striking either of the stops at the end of the travel. When it touches one or the other of the stops the cord is either too short or too long. If it touches both, the travel of the drum is too great, and the cord must be fastened to a point on the reducing motion having less travel.

Keep the drum moving only when taking diagrams. Unhook the cord before putting a paper on the drum. In putting on the card, see that it fits the drum without wrinkles, and fold back the projecting edges over the clip *m* (Fig. 297) so they will not touch the pencil lever.

Before taking the diagram turn on the steam a minute or so to warm up the indicator; then press the pencil lightly on the paper long enough to take a single diagram. Shut the cock, and again press the pencil to the paper. Since the indicator piston is then only subjected to atmospheric pressure, the pencil will make a straight line, called the **atmospheric line.** Disconnect the cord and remove the card. Write on the card the scale of the spring used, the speed of the engine, and any other desired particulars.

If one indicator is used for both ends, first open the three-way cock to admit steam from one end, and take the diagram; open the cock to the other end, and take the diagram from that end. Then, shut off the steam entirely, and take the atmospheric line.

1051. Points and Lines of the Diagram.—In Figs. 302 and 303 are shown indicator diagrams from the top

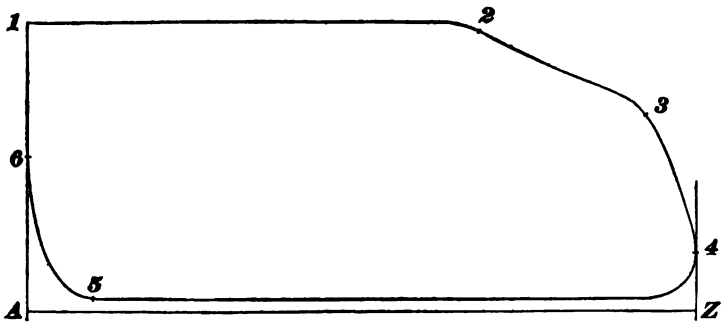


FIG. 302.

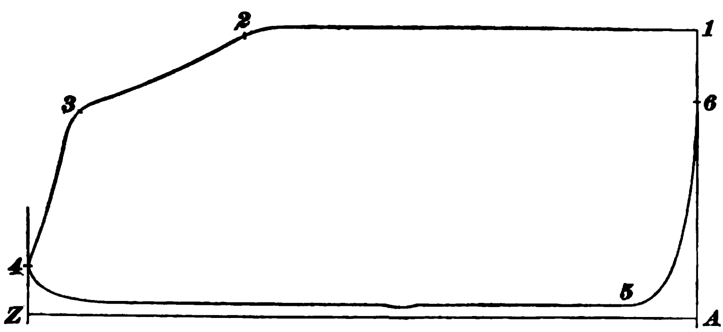


FIG. 303.

and bottom ends of a non-condensing engine. The different points of the stroke are clearly shown. They are as follows:

1 is the beginning of the stroke.
2 is the point of cut-off.
3 is the point of release.
4 is the end of the stroke.
5 is the point of compression.
6 is the point of admission.

The lines included between any two of these points have received special names, which are as follows:

6-1 is the admission line.
1-2 is the steam line.
2-3 is the expansion curve (or expansion line).
3-4-5 is the period of release.
4-5 is the back-pressure line.
5-6 is the compression curve.
A Z is the atmospheric line.

1052. It is sometimes desirable to have the vacuum line (line of no pressure) on the card also. The vacuum line may be drawn below and parallel to the atmospheric line. The distance between them will be $\frac{14.7}{\text{scale of spring}}$ inches. Thus, if the scale of the indicator spring is 30, the vacuum line lies $\frac{14.7}{30} = .49$ inch below the atmospheric line.

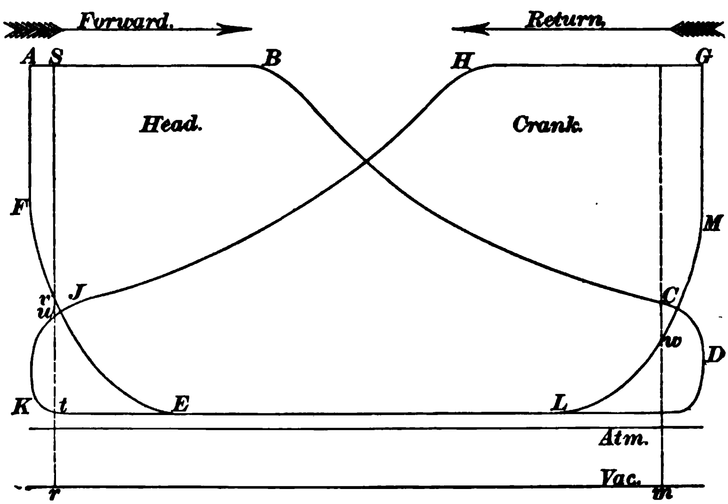


FIG. 304.

If only one indicator is used, the two diagrams in Fig. 304 (taken from a horizontal non-condensing engine) are

taken on the same blank, as shown. With the diagrams placed one over the other, as in the figure, it is very easy to tell exactly what is taking place in the cylinder at any point of the stroke. On the forward stroke the pencil of the indicator describes the line *A B C D* of the head diagram, if the cock is opened to the head end; or it describes the line *K L M*, if the cock is opened to the crank end. Likewise, the lines *G H J K* and *D E F* are described during the return stroke.

The diagrams should always be marked so that there may be no doubt about which is the head end and which the crank-end diagram. In Fig. 304, *A B* is the steam line for the forward stroke, but the only way for a stranger to tell whether it is so or not, is to note that it is marked *head*. The reducing motion is frequently so arranged that the pencil will trace *G H J K L M*, Fig. 304, during the forward stroke.

Suppose the piston is at a position corresponding to *r* on the forward stroke; the pressure (above vacuum) urging the piston forward is *r S*, while the pressure resisting it is *r t*. Hence, the net pressure on the piston is *S t*. Suppose, now, that the piston is at *r* on the return stroke; the pressure at the right urging the piston on is *r u*, while the pressure on the left is *r v*. The net pressure is, therefore, *u v*, and is negative; or, in other words, the resistance is greater than the effort.

1053. A double diagram of this character tells at a glance what is taking place at either end of the cylinder at any point of the stroke. Thus, when the piston is on the forward stroke, in the position corresponding to *m*, the steam in the head end is at the point of release, as shown at *C*. Draw a line through *m* perpendicular to the vacuum line. *C* lies on *A B D*, and since *K L M* is described at the same time as *A B C*, the intersection of the line through *C* with the line *K L M* is the point *w* on the compression line corresponding to *C*; hence, when release occurs in the head end, compression is taking place in the crank end.

READING INDICATOR DIAGRAMS.

1054. The indicator diagram gives valuable information concerning the distribution of the steam. Any fault in the setting of the valves is at once revealed by an inspection of the diagram. The correction of such a fault may result in largely increased economy in the working of the engine.

The form of a good diagram depends largely upon the type of the engine, style of valve, and speed. What would be considered a good diagram from a locomotive or from a high-speed automatic engine, would be considered very poor if taken from a Corliss engine. In general, a diagram taken from an engine with releasing gear of the Corliss or Wheelock type will be regular, and show but little compression. The points of cut-off, release, and compression will be sharply marked.

1055. The diagrams shown in Fig. 305 are what may be expected from this latter type of engine when the valves are correctly set and in good working order. On the other

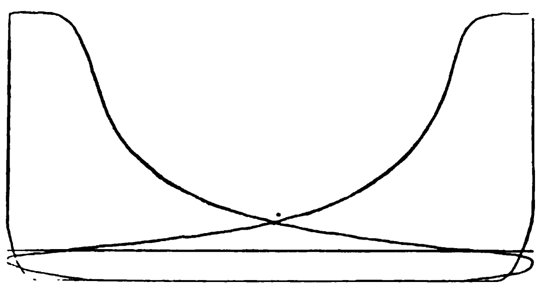


FIG. 305.

hand, Fig. 306 shows the form of diagram that may be expected from an engine of the former type running at 250 or 300 revolutions per minute. On account of the high rotative speed, the lines are irregular, due to the inertia of the moving parts of the indicator. The compression is large, as it should be for engines running at a high speed. The point of cut-off is never very sharply marked.

1056. A typical marine engine card is shown in Fig. 307. This would be considered a very good card among engineers. Owing to the slow motion of the valve

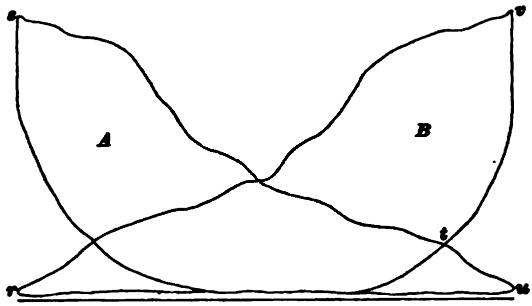


FIG. 306.

the steam is wire-drawn; hence, the steam line slopes downwards. The cut-off, however, is very well marked, especially in the full-line diagrams. These latter are taken with the link nearly in full gear; while the diagrams shown

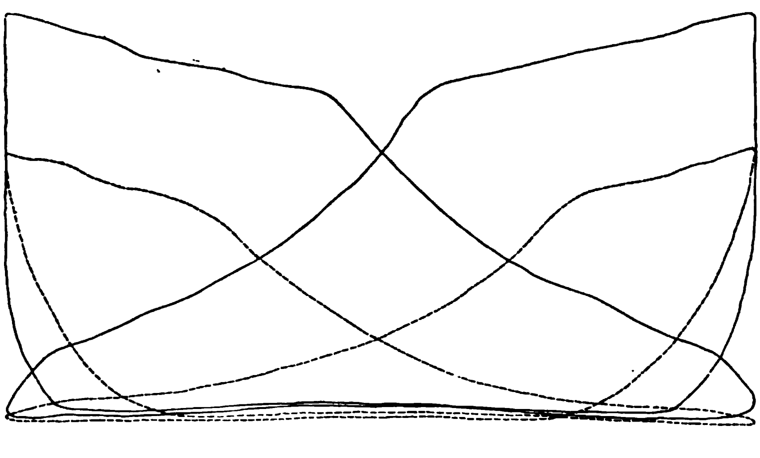


FIG. 307.

in dotted lines indicate what might be expected when cutting off early by means of the link. It will be noticed that all the events are early; furthermore, that since the steam ports are not opened to the same extent as when in full gear,

the steam is throttled, i. e., its pressure is reduced, thus showing far less initial pressure than with the link in full gear.

1057. Diagrams taken from an engine fitted with the See-Marshall valve gear are shown in Fig. 308. The diagrams shown in dotted lines are what might be expected when cutting off early. It will be noticed that the initial pressure is not reduced when cutting off early, as is the case with link-motion diagrams. This is due to the fact that the

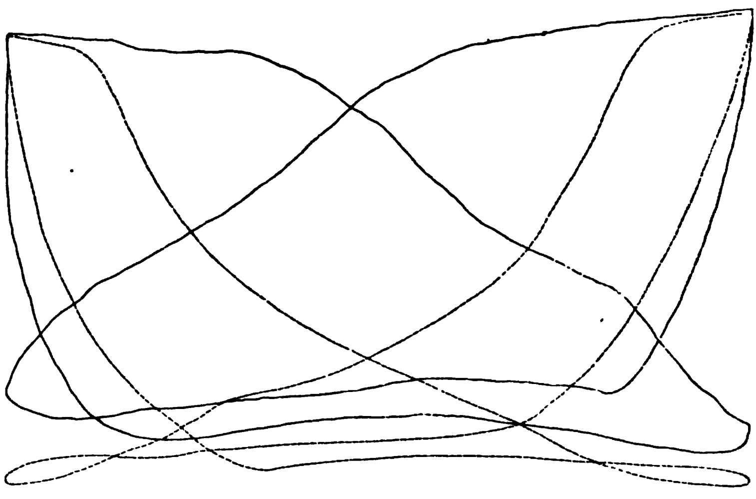


FIG. 308.

valve opens the steam port quite rapidly; it also closes it promptly.

It is readily seen how totally unlike are the diagrams shown in Figs. 305, 306, 307, and 308, yet each would be considered as representing good practice.

1058. Faults in Steam Distribution.—Some of the most common faults revealed by the indicator diagram are given below (I to VIII). In the following diagrams, Figs. 309–313,

1 is the point of admission.
2 is the point of cut-off.
3 is the point of release.
4 is the point of compression.

I. Admission may be too early.
II. Admission may be too late.
III. Cut-off may be too early.
IV. Cut-off may be too late.
V. Release may be too early.
VI. Release may be too late.
VII. Compression may be too early.
VIII. Compression may be too late.

Case I.—The effect upon the diagram of a too-early admission is shown in Fig. 309. It will be seen that the

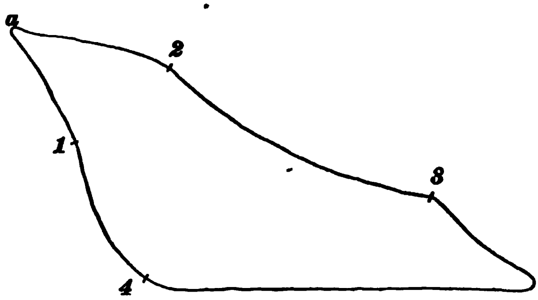


FIG. 309.

admission line *1 a*, instead of being straight and perpendicular to the atmospheric line, as in Figs. 305 and 306, curves backwards. With a single valve like the one previously described, all of the other events, cut-off, release, and compression, are also too early. The remedy is to shift the eccentric on the shaft so as to decrease its angular advance, provided the diagram was taken with the link in full gear.

Case II.—In this case the admission is too late, and the admission line *1 a*, on a diagram, curves forwards, as shown in Fig. 310. The remedy is to increase the angular advance until the admission line *1 a* becomes perpendicular to the atmospheric line. With a single slide valve, in the case of a

too-late admission, the other events at *2*, and particularly *3* and *4*, are also too late.

Case III.—Cut-off too early. See Fig. 318. Here the steam expands below the back-pressure line and forms a loop *C D*. This makes the compression too early also. The figure shown is drawn as if there were no inside lap. With lead, the curve will form a loop, as shown at *A*; without lead, the compression line will extend to *F*. The remedy is to reduce the amount of outside lap. When computing

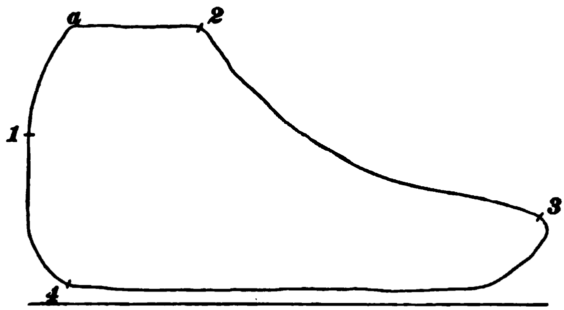


FIG. 310.

the M. E. P. (see Arts. **1063,** etc.) the areas of both loops must be subtracted from the area *A B C A*.

Case IV.—Cut-off too late. See Fig. 311. Here it will be noticed that the terminal pressure is very high. When

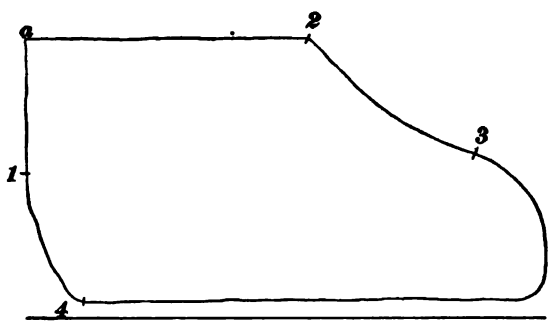


FIG. 311.

this is the case, a great deal of the benefit of expansion is lost, with its consequent waste of steam. It is assumed

that Figs. 318 and 311 were taken from a simple slide-valve engine.

Rule for Cases III and IV.—*Make the cards alike for both ends of the cylinder. For a simple engine and a too-early cut-off, lower the boiler pressure or decrease the number of revolutions per minute. For a too-late cut-off, raise the boiler pressure or increase the number of revolutions per minute. The cut-off is most correctly equalized by making the terminal pressure at both ends of the cylinder the same. For a reversible engine, cut off earlier or later by means of the link or any other means provided for so doing.*

Case V.—See Fig. 309.

Case VI.—See Fig. 310.

Rule for Cases V and VI.—*Arrange the valves so that one-half of the fall of pressure occurs before the piston starts back on the return stroke.*

Case VII.—Compression too early.

Fig. 312 shows the effects of too-early compression. A loop is formed, as shown in Fig. 318. The area of this loop must be subtracted from the larger area in computing the

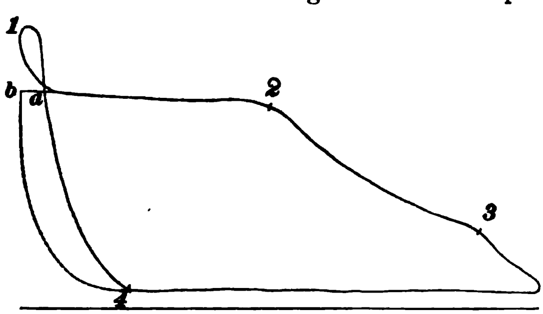


FIG. 312.

M. E. P. (see Arts. **1063**, etc.). With the same cut-off and the proper amount of compression, the area gained would be *a b 4 a* (included between the line *4 a* and the dotted line *a b 4*) plus the area of the loop *a 1*. The remedy in this case is to decrease the amount of inside lap. The required amount of compression depends upon the speed of the engine,

slow-running engines not requiring so much compression as the high-speed engines. In any case the compression line should not extend above the initial or boiler pressure.

It is good practice to compress to about $\frac{9}{10}$ the initial pressure with high-speed engines, $\frac{5}{10}$ with medium-speed engines, and from $\frac{2}{10}$ to $\frac{3}{10}$ with slow-speed engines.

1059. All of the above faults are due to valve setting, and can be detected as soon as the indicator is applied.

With a plain slide valve it will be found that if one of the events of the stroke is early or late, the others are also liable to be so; for example, an early admission usually produces an early release and compression.

When cards are taken from an engine fitted with link motion, the cards being taken for the purpose of detecting any fault in valve setting or steam distribution, the link should be placed in full gear before the cards are taken.

When the steam line falls abruptly, as shown in Fig. 309, it may be inferred that the steam is throttled, i. e., either the steam pipe or the port is too small for the required duty. A very high piston speed would also produce this effect.

The diagram shown in Fig. 313 indicates that the back

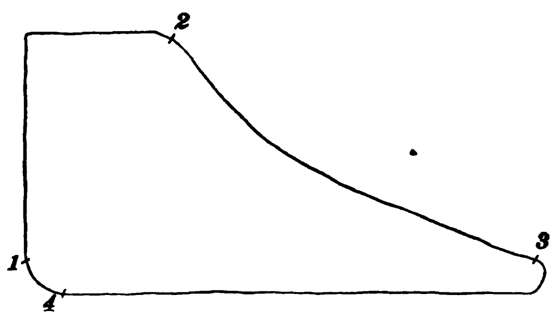


FIG. 313.

pressure is excessive (note the distance between the atmospheric line and the lower line of the diagram). This may be the case when the exhaust port is too small or when the exhaust steam is used for heating purposes, and in consequence has to be pushed through coils of pipe.

1060. The Expansion Line.—Very often the character of the expansion line of the indicator diagram may give information concerning the action of steam in the cylinder. It is, therefore, often desirable to draw the theoretical expansion line, that is, the line which the steam pressure would follow if it varied inversely as the volume. A convenient method of drawing the theoretical expansion line is shown in Fig. 314. The indicator diagram *E C K L* is given as shown in the figure. The atmospheric line *M N* is also taken by the indicator. First draw the vacuum line *O X*, as explained in Art. **1052,** and on it project the two ends

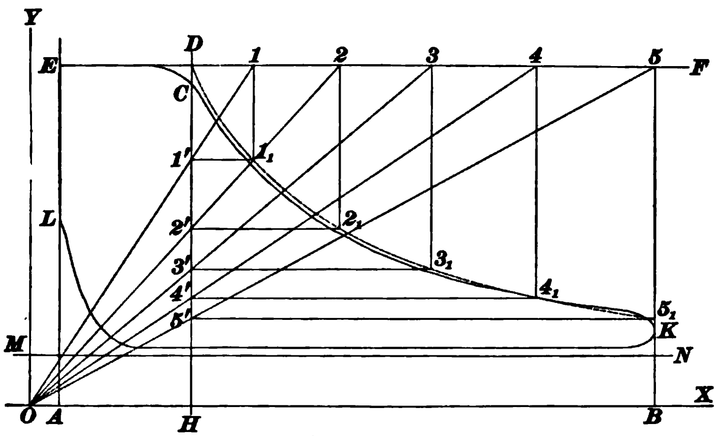


FIG. 314.

of the diagram at *A* and *B*; then, *A B* is the length of the diagram. Lay off *O A* to represent the clearance as explained in connection with Fig. 285, Art. **994;** draw the vertical line *O Y*. Prolong the steam line *E D* to *F*. Locate the point of cut-off *C*, and project it vertically to *D* in the line *E F*. Draw the vertical line *D H*. Now, through the point *O*, draw at random the lines *O 1*, *O 2*, *O 3*, etc., cutting the lines *D H* and *E F* in the points *1'*, *2'*, *3'*, etc., and *1*, *2*, *3*, etc., respectively. Through point *1* draw a vertical line, and through *1'*, a horizontal line; they will intersect in 1_1, which will be a point on the required theoretical expansion curve. In a similar manner, points 2_1, 3_1, 4_1, and 5_1 are found,

and the expansion line is drawn through them (shown by a dotted line in the figure).

It will be noticed in this particular case that at cut-off, and for part of the stroke after cut-off, the actual expansion line falls below the theoretical line, while towards the end of the stroke, the actual line rises above the other. This shows that during the first part of the stroke steam is condensed by the cold cylinder walls, but is reevaporated near the end of the stroke.

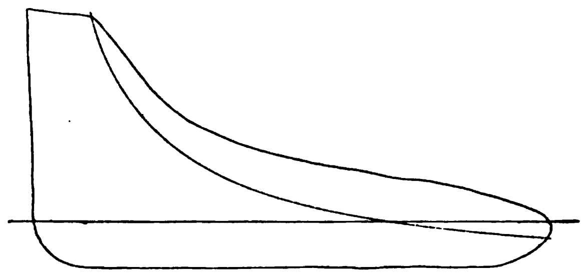


FIG. 315.

Where the expansion line rises very markedly above the theoretical curve, as shown in Fig. 315, it is evident that the valve leaks, and allows steam to enter after cut-off.

The theoretical expansion line, as drawn in Fig. 314, is called the **equilateral hyperbola.**

1061. Determining the Point of Cut-Off.—It is sometimes very difficult to determine exactly the point of cut-off from the indicator diagram, especially when the engine has a high rotative speed. The most general method of determining it is to prolong the expansion line upwards, following the general shape of the curve, and note where it leaves the actual line of the diagram; then take the point of cut-off at or very near the point of deviation. The above can be performed with the aid of a flat wooden implement known as an "irregular curve."

The rounding of the diagram near the point of cut-off is caused, as before stated, by the slowness of the valve's motion in cutting-off.

HORSEPOWER.

1062. The **horsepower** developed by the engine may be found directly from the area of the indicator diagram, as shown in Art. **938.** It is more convenient, however, to use the diagram to find the "mean effective pressure" exerted on the piston.

1063. The **mean effective pressure,** or M. E. P., is defined as the average net pressure urging the piston forwards during its entire stroke in one direction. The mean effective pressure may be found in two ways:

1064. 1. The area of the diagram in square inches may be found by an instrument called the planimeter; *the M.E.P. is then found by dividing the area of the diagram in square inches by the length of the diagram in inches, and multiplying by the scale of the spring.*

EXAMPLE.—The area of the diagram is 4.2 sq. in., and the length is 3.5 in.; a 40 spring being used, find the M. E. P.

SOLUTION.— $\frac{4.2}{3.5} \times 40 = 48$ lb. per sq. in., M. E. P. Ans.

2. Where a planimeter is not available, the following method of finding the M. E. P. is fairly rapid and accurate:

Draw tangents to each end of the diagram perpendicular to the atmospheric line. Divide the horizontal distance between the tangents into 10 or more equal parts. (10 or 20 parts are the most convenient, but any other number may be used.) Indicate by a dot on the diagram the center of each division, and draw lines through these dots, parallel to the tangents, from the upper line to the lower line of the diagram. On a strip of paper mark off successively the lengths of these lines, the total length thus representing the sum of all the lines. Divide this total length by the number of lines used and multiply the quotient by the scale of the spring. The result will be the M. E. P. This method is the same as that used in Art. **941** *in finding the area of the diagram.*

EXAMPLE.—The bottom-end diagram shown in Fig. 303 is reproduced in Fig. 316; its projection upon the atmospheric line is $A\ Z$; that is, lines perpendicular to this line, drawn through the extreme

ends *1* and *4* of the diagram, cut it (the atmospheric line) in *A* and *Z*. *A Z* is divided, in this case, into 14 equal spaces. The length

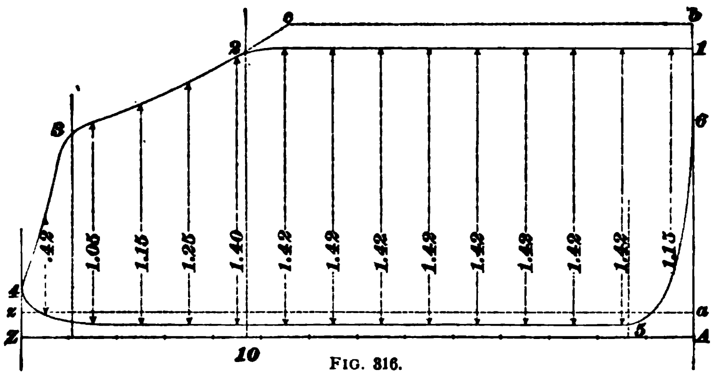


FIG. 316.

of each of the perpendicular lines drawn through the diagram opposite the centers of these spaces is marked on the line itself, and the sum of these lengths is 18.11 inches. The scale of the spring used in obtaining the diagram was 40 pounds; therefore, $\frac{18.11}{14} \times 40 = 51.74$ pounds per square inch = the M. E. P. of the bottom-end diagram.

EXAMPLE.—The projection of the top-end diagram of Fig. 302 upon the atmospheric line (see Fig. 317) is the distance *A Z*, and it is divided, in this case, into 14 equal spaces. The length of each of the perpendicular lines drawn through the diagram opposite the centers of these spaces is marked on the line itself, and the sum of these lengths is 17.78 inches. The scale of the spring is 40 pounds; therefore, $\frac{17.78}{14} \times 40 = 50.8$ pounds per square inch = the M. E. P. of the top-end diagram.

Therefore, the M. E. P. in the cylinder during a complete revolution of the crank is $\frac{51.74 + 50.8}{2} = 51.27$ pounds per square inch.

1065. The reason for dividing the diagram into 10 parts instead of some other number is that it shortens the work of calculation. Thus, in the two examples just given, if the number of divisions had been 10 instead of 14, and the sum of the ordinates had been 12.94 inches, the mean ordinate would have been $\frac{12.94}{10} = 1.294''$, and the M. E. P., $1.294 \times 40 = 51.76$ lb. per sq. in. All that is necessary is to add the ordinates and shift the decimal point one place

to the left to obtain the mean ordinate when the diagram is divided into 10 equal parts. This method saves the time required to divide by some inconvenient number, such as 14.

In Figs. 316 and 317, the vertical line *a b* represents the boiler pressure, and, therefore, the dotted line *b c* is the line

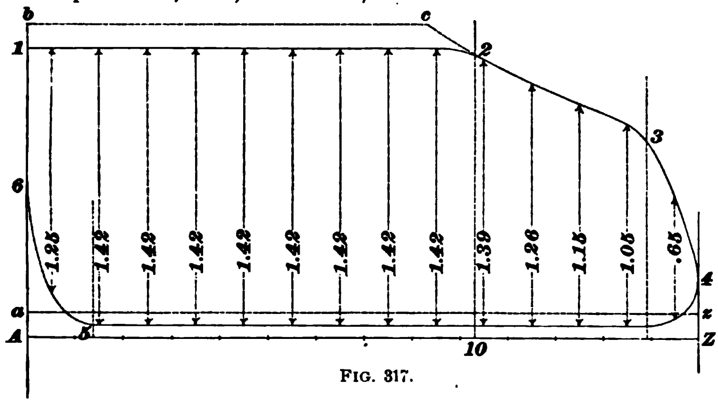


FIG. 317.

that the indicator pencil would trace if the full boiler pressure were maintained until point of cut-off. The line *b c* is not drawn by the indicator as ordinarily used; it has been added for sake of illustration.

1066. Sometimes the expansion line of the diagram will fall below the back-pressure line, as shown in Fig. 318. In

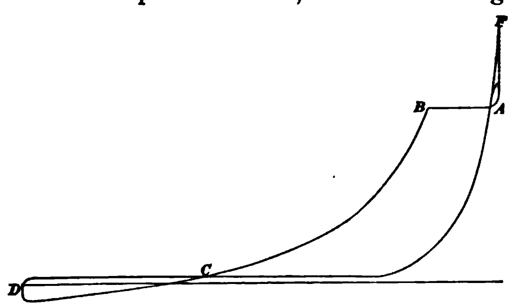


FIG. 318.

such a case the area of the loop *C D*, and also that of the loop at *A*, must be subtracted from the remainder of the diagram *A B C*. When the planimeter is used, the subtraction is made automatically by the instrument, but when the

diagram is divided into parts, as before described, by the method of ordinates, the sum of the ordinates included between C and D must be subtracted from the sum of those included between C and A. The result divided by the total number of spaces will give the mean ordinate; multiplying this by the scale of the spring will give the M. E. P., as before.

We have now all the material required for finding the work done in the engine cylinder expressed in horsepower units.

1067. Work is the product of force into the distance through which it moves. In the case of the engine cylinder, the total force is the M. E. P. per square inch multiplied by the area of the piston; and the distance moved through in one minute is the number of strokes per minute multiplied by the length of the stroke.

Rule 180.—*To find the* **indicated horsepower** *developed by the engine, multiply together the M. E. P. per square inch, the area of the piston, the length of stroke, and the number of strokes per minute. This gives the work per minute in foot-pounds. Divide the product by 33,000; the result will be the indicated horsepower of the engine.*

Let I. H. P. = indicated horsepower of engine;
P = M. E. P. in pounds per square inch;
A = area of piston in square inches;
L = length of stroke in feet;
N = number of strokes per minute.

Then, the above rule may be expressed thus:

$$\text{I. H. P.} = \frac{P L A N}{33{,}000}.$$

The number of strokes per minute is twice the number of revolutions per minute. For example, if an engine runs at a speed of 210 revolutions per minute, it makes 420 strokes per minute. A few types of engines, however, are single-acting; that is, the steam only acts on one side of the piston. Such are the Westinghouse, the Willans, and others. In this case, only one stroke per revolution does work, and,

consequently, the number of strokes per minute to be used in the above rule is the same as the number of revolutions per minute.

EXAMPLE.—The diameter of the piston of an engine is 10 inches, and the length of stroke, 15 inches. It makes 250 revolutions per minute, with a M. E. P. of 40 pounds per square inch. What is the horsepower ?

SOLUTION.—As it is not stated whether the engine is single or double-acting, assume that it is double-acting. Then, the number of strokes is $250 \times 2 = 500$ per minute. Applying rule **180**,

$$\text{I. H. P.} = \frac{PLAN}{33,000} = \frac{40 \times \frac{15}{12} \times (10^2 \times .7854) \times 500}{33,000} = 59.5 \text{ H. P.}$$

EXAMPLE.—In Fig. 319 are shown two indicator diagrams taken from an 18″ × 20″ non-condensing engine, making 200 revolutions per minute. The scale of the spring is 60. Compute the mean effective pressure and the horsepower. The engine is double-acting.

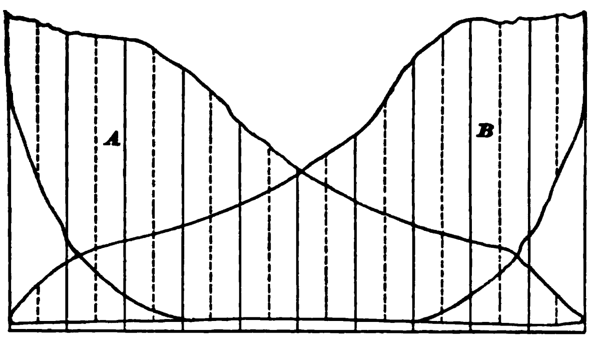


FIG. 319.

SOLUTION.—Divide the diagrams into 10 equal parts, as shown by the full lines. Then, as previously directed, draw lines (see dotted lines in the figure) perpendicular to the atmospheric line through the middle points of each of the ten equal divisions. Measuring the lengths of all of the dotted lines and adding them together, we find the sum of the lengths for diagram A is 7.8″, and for diagram B, 7.84″. Dividing each of these results by 10 and multiplying by the scale of the spring, we have $\frac{7.8}{10} \times 60 = 46.8$ lb. per sq. in. = M. E. P. for diagram A, and $\frac{7.84}{10} \times 60 = 47.04$ lb. per sq. in. = M. E. P. for diagram B. The average M. E. P. for both cards is $\frac{46.8 + 47.04}{2} = 46.92$ lb. per sq. in.

To find the horsepower, the value for the M. E. P. must be substituted for P in the formula I. H. P $= \frac{P\,L\,A\,N}{33,000}$. Reducing the stroke to feet, and substituting the values of P, L, A, and N, we have

$$\frac{46.92 \times \frac{20}{12} \times (18^2 \times .7854) \times (200 \times 2)}{33,000} = 241.21 \text{ H. P.} \quad \text{Ans.}$$

1068. Approximate Determination of M. E. P.—To approximately determine the M. E. P. of an engine, when the point of apparent cut-off is known and the boiler pressure, or the pressure per square inch in the boiler from which the supply of steam is obtained, is given:

Rule 181.—*Add 14.7 to the gauge pressure, and multiply the result by the number opposite the fraction indicating the point of cut-off in Table 34. Subtract 17 from the product and multiply by .9. The result is the M. E. P. for good simple non-condensing engines;*

or, letting p = gauge pressure;
k = a constant (see Table 34);
M. E. P. = mean effective pressure.

Then, M. E. P. $= .9\,[k(p + 14.7) - 17]$.

If the engine is a simple condensing engine, subtract the pressure in the condenser instead of 17. The fraction indicating the point of cut-off is obtained by dividing the distance that the piston has traveled when the steam is cut off by the whole length of the stroke; i. e., it is the apparent cut-off. For a $\frac{2}{3}$ cut-off, and 92 pounds gauge pressure in the boiler, the M. E. P. is, by the formula just given, $.9[.917(92 + 14.7) - 17] = 72.6$ lb. per sq. in.

TABLE 34.

Cut-Off.	Constant.	Cut-Off.	Constant.	Cut-Off.	Constant.
$\frac{1}{6}$	.566	$\frac{3}{8}$	.771	$\frac{2}{3}$	.917
$\frac{1}{5}$	.603	.4	.789	.7	.926
$\frac{1}{4}$	.659	$\frac{1}{2}$	.847	$\frac{3}{4}$	.937
.3	.708	.6	.895	.8	.944
$\frac{1}{3}$	.743	$\frac{5}{8}$	.904	$\frac{7}{8}$	.951

EXAMPLE.—Find the approximate I. H. P. of a 9″ × 12″ non-condensing engine cutting off at $\frac{1}{4}$ stroke, and making 240 revolutions per minute. The boiler pressure is 80 pounds, gauge.

SOLUTION.—$80 + 14.7 = 94.7$. Using rule **181,** and Table 34, the constant for $\frac{1}{4}$ cut-off is .847, and $.847 \times$ boiler pressure $= .847 \times 94.7 = 80.21$. M. E. P. $= (80.21 - 17) \times .9 = 56.89$ lb. per sq. in. Then, from rule **180,**

$$\text{I. H. P.} = \frac{P\,L\,A\,N}{33{,}000} = \frac{56.89 \times \frac{12}{12} \times (.7854 \times 9^2) \times 240 \times 2}{33{,}000} = 52.64 \text{ H. P.}$$

Ans.

1069. Piston Speed.—The product $L\,N$ of rule **180** gives the total distance traveled by the piston in one minute. This is called the **piston speed.** It is usual to take the stroke in inches. Then, to find the piston speed, multiply the stroke in inches by the number of strokes and divide by 12, or letting S represent the piston speed, $S = \frac{l\,N}{12}$, where l is the stroke in inches. But $N = 2\,R$ where R represents the number of revolutions per minute. Hence,

$$S = \frac{l\,N}{12} = \frac{l \times 2\,R}{12} = \frac{l\,R}{6}.$$

Rule 182.—*To find the piston speed of an engine, multiply the stroke in inches by the number of revolutions per minute and divide the product by 6.*

EXAMPLE.—An engine with 52-inch stroke runs at a speed of 66 revolutions per minute. What is the piston speed?

SOLUTION.—By rule **182,** $S = \frac{l\,R}{6} = \frac{52 \times 66}{6} = 572$ ft. per min. Ans.

The piston speeds used in modern practice vary from 300 to 1,400 feet per minute, according to the type of engine.

1070. Friction Horsepower: Net Horsepower.—Rule **180** gives the indicated horsepower, or I. H. P.; that is, the total horsepower developed in the engine cylinder. A part of the I. H. P. is used in overcoming the friction of the moving parts of the engine. The remainder is available for doing the required work.

1071. The power absorbed by the engine itself is termed the **friction horsepower.**

1072. The power available for doing useful work is termed the **net,** or **actual, horsepower.**

The actual horsepower of any engine is found by first computing its I. H. P. from a set of indicator diagrams taken while the engine is running under full load, and then subtracting from this the I. H. P. computed from a set of indicator diagrams taken when the engine is running under no load, but making the same number of revolutions per minute as above. The horsepower developed by the engine in this last case will only be sufficient to keep the working parts of the engine in motion at the same speed. To obtain the friction horsepower of a screw propeller engine, the tailshaft (the length of shafting carrying the propeller) will have to be uncoupled, or the propeller unshipped. With a paddle-wheel engine, the buckets of the paddle-wheels must be unshipped.

EXAMPLE.—Indicator diagrams taken from an engine while running under full load, and having a piston speed of 498 feet per minute, show an *indicated horsepower* of 242.7. With the same piston speed, and running under no load, the indicator diagrams show an *indicated horsepower* of 75.2. Then, $242.7 - 75.2 = 167.5$ = the *actual horsepower* of the engine.

1073. The **mechanical efficiency** of an engine is the ratio of the *actual horsepower* to the *indicated horsepower;* or it is the per cent. of the mechanical energy developed in the cylinder which is utilized in the doing of useful work.

To find the efficiency of an engine, when the *indicated* and *actual horsepowers* are known:

Rule 183.—*Divide the actual horsepower by the indicated horsepower.*

Let N. H. P. = the net, or actual, horsepower;
I. H. P. = the indicated horsepower;
E_m = efficiency of engine.

Then, $$E_m = \frac{\text{N. H. P.}}{\text{I. H. P.}}$$

EXAMPLE.—The indicator diagrams taken from an engine running under full load show the I. H. P. to be 238.5. The diagrams taken when the engine is running under no load show a horsepower of 39.7. (*a*) What is the net H. P. developed by the engine? (*b*) What is the efficiency of the engine?

SOLUTION.—(*a*) Net H. P. = I. H. P. – friction H. P. = 238.5 – 39.7 = 198.8. Ans.

(*b*) By rule **183** the efficiency is

$$\frac{\text{N. H. P.}}{\text{I. H. P.}} = \frac{198.8}{238.5} = 83.4\%. \quad \text{Ans.}$$

The mechanical efficiency of a good engine is from 75 to 90 per cent. It should not be confounded with the mechanical efficiency of the propelling instrument, for this latter represents the percentage of the power supplied to it; that is, usefully expended in projecting a stream of water. If the efficiency of the engine and of the propelling instrument were combined, we should have the efficiency of the whole propelling apparatus. This is generally from 60 to 65 per cent., and is the real measure of the vessel's economy.

EXAMPLES FOR PRACTICE.

1. The mean ordinates of two diagrams taken from the two ends of the cylinder of an 18" × 20" non-condensing engine running at 200 R. P. M. (revolutions per minute) are, respectively, .72" and .76" long. The scale of spring being 80, what is the horsepower of the engine? Ans. 304.335 H. P.

2. The area of an indicator diagram, as found by the planimeter, is 2.76 square inches. The length of the diagram is 2.4 inches, and the scale of the spring is 30. What is the M. E. P.?
Ans. 34½ lb. per sq. in.

3. The indicator diagrams from a tugboat engine show a M. E. P. of 27.3 pounds per square inch. The engine has a 26" × 48" cylinder, and makes 68 revolutions per minute. Calculate the I. H. P. developed by the engine. Ans. 238.94 H. P.

4. Find the I. H. P. developed by an 8" × 12" engine running at 260 revolutions per minute, the average M. E. P. being 32.61 pounds per square inch. Ans. 25.83 H. P.

5. (*a*) What is the piston speed of the engine of example 3? (*b*) Of the engine of example 4?

Ans. $\begin{cases} (a)\ 544 \text{ ft.} \\ (b)\ 520 \text{ ft.} \end{cases}$

6. The M. E. P. from the diagrams of an engine running under full load is 43.2 pounds per square inch. The M. E. P. from the diagrams when under no load is 5.7 pounds per square inch. The engine has a 16" × 20" cylinder, and makes 180 revolutions per minute. Find (*a*) the I. H. P. developed; (*b*) the friction H. P.; (*c*) the net H. P.; (*d*) the mechanical efficiency of the engine.

Ans. { (*a*) 157.92 H. P.; (*b*) 20.84 H. P.; (*c*) 137.08 H. P.; (*d*) 86.8%.

7. An 18" × 24" engine running at 150 revolutions per minute cuts off steam at 15" of its stroke. Find (*a*) the probable M. E. P., and (*b*) the probable I. H. P. Gauge pressure is 70 pounds.

Ans. { (*a*) 53.61 lb. per sq. in.; (*b*) 248.04 H. P.

STEAM CONSUMPTION.

1074. The indicator diagram also enables us to find approximately the amount of steam consumed by the engine.

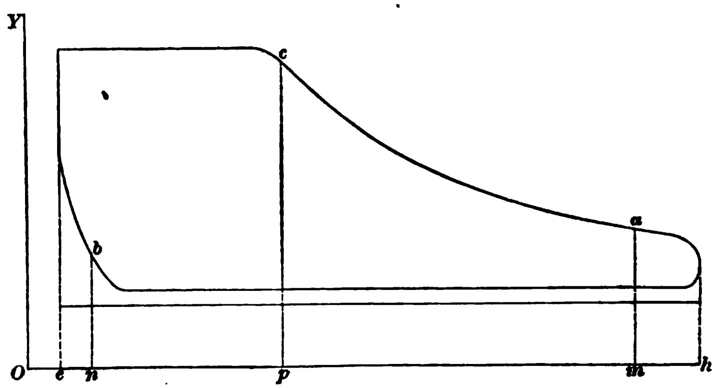


FIG. 320.

In referring to the steam consumption, it is customary to take as a unit the *steam consumed per horsepower per hour*.

Take a point *a* on the expansion line before the release takes place (see Fig. 320); measure the pressure from the vacuum line, and from column 6 of the steam table find the weight of a cubic foot of steam at that pressure. The cubic contents of the cylinder (including the clearance) up

to the point a multiplied by the weight per cubic foot will give the weight of steam in the cylinder at this instant. This weight would be the steam consumed per stroke were it not for two circumstances: 1. When the fresh steam from the boiler enters the cylinder it comes in contact with the cylinder walls which have been cooled down by the exhaust steam. (A glance at the steam table shows that the exhaust steam is at a very much lower temperature than the fresh steam.) Consequently, part of the incoming steam condenses, and, of course, the indicator diagram takes no account of this condensed steam. Hence, the steam actually in the cylinder is less than originally entered from the boiler, because part of the original steam has changed to water. 2. On account of the closure of the exhaust port, some steam is compressed and saved.

1075. To find the weight of the steam saved by compression, take a point b on the compression curve, measure its pressure from vacuum as before, and compute the weight of the steam in the cylinder up to b. Subtract this from the weight first obtained, and the difference will be the weight of steam per stroke accounted for by the indicator. Multiply this weight per stroke by the number of strokes per hour, and divide by the I. H. P. of the engine. The result will be the steam used per I. H. P. per hour.

EXAMPLE.—Fig. 320 represents an indicator diagram taken from an engine having an 18" × 24" cylinder, running at 120 revolutions, and developing 130 horsepower. The clearance is 5%. Find the steam consumption per I. H. P. per hour.

SOLUTION.—Project the two ends of the diagram perpendicularly upon the vacuum line $O\,h$, as at e and h; $e\,h$ is then the length of the diagram. Lay off $e\,O$ equal to the clearance; that is, equal to 5% of $e\,h$. Draw $O\,Y$ perpendicular to $O\,h$. Take the point a near the point of release, and measure the distances $a\,m$ and $O\,m$. Take the point b somewhere on the compression line, and measure the distances $b\,n$ and $O\,n$. These measurements are found to be

$$a\,m = 0.71 \text{ inch;}$$
$$O\,m = 3.17 \text{ inches;}$$
$$b\,n = 0.6 \text{ inch;}$$
$$O\,n = \tfrac{1}{4} \text{ inch.}$$

The length of the diagram $= c\,h = 3\frac{1}{3}$ inches; the length of the stroke is 2 feet. Hence, each inch of the length of the diagram equals $\frac{2}{3\frac{1}{3}} = .6$ foot of stroke. The scale of the indicator spring is 45. Hence, the above measurements reduced to pressures in pounds per square inch and feet of stroke become

$$\begin{aligned} a\,m &= .71 \times 45 = 31.95 \text{ pounds;} \\ b\,n &= .6 \times 45 = 27 \text{ pounds;} \\ O\,m &= 3.17 \times .6 = 1.9 \text{ feet;} \\ O\,n &= \tfrac{1}{3} \times .6 = .2 \text{ foot.} \end{aligned}$$

The area of the piston is $18^2 \times .7854 = 254.47$ sq. in. $= \frac{254.47}{144} = 1.767$ sq. ft. Consequently, the volume of steam in the cylinder, when the piston is at the point represented by a, is $1.9 \times 1.767 = 3.3573$ cu. ft. The volume, when the piston is at b, is $.2 \times 1.767 = .3534$ cu. ft. The weight of a cubic foot of steam at an absolute pressure of 31.95 pounds per sq. in. is found from the steam table to be .078723 pound; and at a pressure of 27 pounds, the weight is .067207 pound. Hence, the weight of the steam in the cylinder is $.078723 \times 3.3573 = .264297$ pound; while the weight of steam saved by compression is $.067207 \times .3534 = .023751$ pound. The steam used per stroke is, therefore, $.264297 - .023751 = .240546$ pound. To find the amount used per I. H. P. per hour, multiply the weight used per stroke by the number of strokes per hour and divide by the I. H. P. Therefore, the required weight is $\frac{.240546 \times 120 \times 2 \times 60}{130} = 26.645$ pounds. Ans.

1076. Suppose the weight of the steam in the cylinder to be calculated by taking the point c near the point of cut-off, $c\,p = 1.59$ inches $= 1.59 \times 45 = 71.55$ lb.; $O\,p = 1\frac{1}{3}$ in. $= \frac{4}{3} \times .6 = .8$ ft. of stroke. The volume of steam in the cylinder when the piston is at c is, therefore, $.8 \times 1.767 = 1.4136$ cu. ft. One cubic foot of steam at the pressure of 71.55 pounds, absolute, weighs .168009 pound. The weight of the steam in the cylinder is, therefore, $.168009 \times 1.4136 = .237498$ lb. Subtracting the steam saved by compression, the steam used per stroke is $.237498 - .023751 = .213747$ lb., and the steam per I. H. P. per hour is

$$\frac{.213747 \times 120 \times 2 \times 60}{130} = 23.677 \text{ lb.}$$

1077. Now, unless the valve leaks, the weight of the steam when the piston is at a can be no greater than when

it is at c, since no fresh steam has been allowed to enter; but the calculation shows that there is .264297 pound in the cylinder when the piston is at a, and only .237498 pound when the piston is at c. This shows that $.264297 - .237498 = .026799$ pound has been condensed to water by the time the piston has arrived at c, but has been reevaporated before the piston arrives at a. Hence, by calculating the water consumption at cut-off and then at release, a good idea of the amount of cylinder condensation may be obtained. If the steam used by the engine be actually caught and weighed, and then compared with the weight as calculated from release, an idea may be obtained of the amount of condensation at release. The computed consumption is always less than the actual consumption.

1078. Where there is a sufficient amount of compression, the work may be simplified by taking the two points a and b at the same height above the vacuum line, as

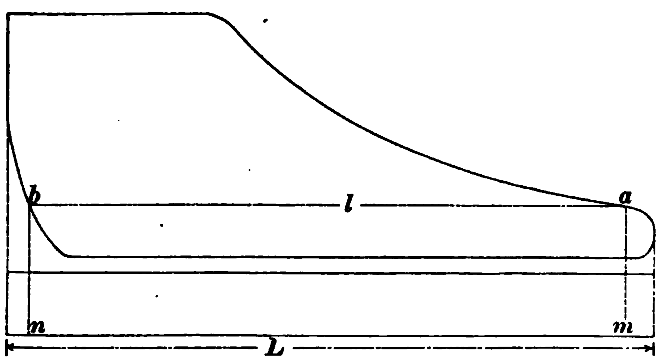


FIG. 321.

shown in Fig. 321. Since the absolute pressure at a and b is the same, the clearance may be left entirely out of account, and the volume to be used in the computation will be $\frac{l}{L}$ times the volume of the cylinder, or, in other words, $\frac{l}{L} \times$ length of stroke $\times$ area of piston. When this method is

used, the steam consumption may be found directly from the formula :

$$Q = \frac{13,750\, l\, W}{P L},$$

in which Q is the number of pounds of steam consumed per horsepower per hour; W, the weight of a cubic foot of steam at the absolute pressure a, and P, the M. E. P.

Expressing the formula in words, we have the following rule:

Rule 184.—*Take two points, one on the expansion line and one on the compression line, both equally distant from the vacuum line. Find the pressure of the steam at these points, and from the steam table find the weight of a cubic foot of steam at that pressure. Multiply this weight by the distance between the two points and by 13,750. Divide the product by the M. E. P. and by the length of the diagram. The result will be the pounds of steam consumed per I. H. P. per hour, as shown by the diagram.*

EXAMPLE.—From a diagram taken from an $18\frac{1}{2}'' \times 30''$ engine, the following measurements were obtained (see Fig. 321): $a\,m = .667$ inch; $l = 3.08$ inches; $L = 3.5$ inches; M. E. P. = 35 pounds; spring, 45. What is the steam consumption per I. H. P. per hour?

SOLUTION.—The indicator diagram being taken with a 45 spring, the pressure at a is $45 \times .667 = 30$ pounds, absolute. The weight of a cubic foot of steam at this pressure is .0742 pound. Using the above rule,

$$Q = \frac{13,750\, l\, W}{P L} = \frac{13,750 \times 3.08 \times .0742}{35 \times 3.5} = 25.65 \text{ lb.} \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE.

1. Size of engine, $12'' \times 20''$; length of diagram L, 3.4"; length l, $2\frac{1}{4}''$; height $a\,m$, $\frac{2}{3}''$; R. P. M., 230; spring, 30; M. E. P., 18 lb. per sq. in. What is the steam consumption per I. H. P. per hour ?

Ans. 25.63 lb. per I. H. P. per hour.

2. Size of engine, $12'' \times 12''$; M. E. P., 51.1; length of diagram L, 2.6"; length l, 1.8"; height $a\,m$, .7"; R. P. M., 350; spring, 70. What is the steam consumption per I. H. P. per hour ?

Ans. 21.92 lb. per I. H. P. per hour.

3. If in the above engine, example 2, the pressure at cut-off is 110 lb., absolute; the clearance is 8%; the length of the diagram to the point of cut-off is .7"; the pressure at a point on the compression curve is 49 lb., absolute, and the distance of this point from the end of the diagram is .14", what is the steam consumption per I. H. P. per hour at cut-off? Ans. 19.44 lb. per I. H. P. per hour.

EFFICIENCY.

1079. Efficiency of Heat Engines.—The combustion of a pound of good coal gives out about 14,000 B. T. U. of heat. In a good boiler it is possible to transfer, perhaps, 11,000 or even 12,000 of these B. T. U. to the contained water, the remainder being lost partly through the gases which pass through the stack into the atmosphere and partly by radiation, etc. Each of these B. T. U. is equivalent to 778 foot-pounds of work, but no heat engine yet devised has been able to convert more than a small fraction of this heat into work.

1080. It has been shown that heat energy consists of the motions of the molecules of the hot body. In order, therefore, to change into work *all* the heat energy contained in a pound of steam, it would be necessary to take from the steam all of its molecular motion; in other words, to lower its temperature until its molecules reached a state of rest. It can be shown by experiment that the temperature at which a body would be in such a state is about 460° below zero, Fahrenheit. This point is called the **absolute zero** of temperature. Temperatures measured from this zero point are called **absolute temperatures.**

Absolute temperatures are obtained by adding 460° to the ordinary temperature. That is,

absolute temperature = ordinary temperature + 460°.

For example, the ordinary temperature of steam at atmospheric pressure is 212°. The absolute temperature is 460 + 212 = 672°. This means that if steam or other gas at 212° could be cooled down 672°, the molecules would cease moving, and there would be no heat in the body.

1081. It is at once evident that it is practically impossible to cool the steam leaving the engine cylinder to even approximately so low a temperature; long before reaching the absolute zero, the steam would be changed to ice. This explains why it is impossible for an engine to obtain 778 foot-pounds from each B. T. U. conveyed to it.

Let t_1 denote the ordinary temperature of the steam entering the engine cylinder, and let T_1 represent the corresponding absolute temperature. Likewise, let t_2 and T_2, respectively, represent the ordinary and the absolute temperature of the steam leaving the cylinder. If we take the amount of energy contained in the entering steam as proportional to the absolute temperature T_1, then, it may be proven that the amount of work extracted by the engine is proportional to $T_1 - T_2$; or

$$\text{useful work} : \text{total energy} = T_1 - T_2 : T_1.$$

The thermal efficiency of an engine is the ratio of the useful work to the total energy; therefore,

$$\text{efficiency} = \frac{T_1 - T_2}{T_1}.$$

1082. The above reasoning may be perhaps made clearer by comparing the temperature of steam to the "head" of a water-power. If a source of water is 1,500 feet above the sea-level, the work or potential energy of the water is represented by the head of 1,500 feet. But, probably, the water-wheel to which the water is led is itself 1,400 feet or more above the sea-level; consequently, only 100 feet of the 1,500 is available "head," and the efficiency of the arrangement can not exceed $\frac{1,500 - 1,400}{1,500} = \frac{1}{15}$. Absolute zero may be called the "sea-level" of temperature, and the temperature of the atmosphere surrounding the engine is generally much lower than the temperature at which the steam can be exhausted from the engine.

The above expression for the efficiency applies equally well to steam engines, hot-air engines, gas engines, or any other form of heat engine.

CONDENSERS.

CONDENSATION.

1083. It is plain that there are only two ways of increasing the efficiency of the steam engine; namely, either raise the temperature T_1 of the live steam, or lower the temperature T_2 of the exhaust steam; T_1 may be raised by increasing the boiler pressure; T_2 may be lowered by using a **condenser.**

It is the common practice among marine engineers to refer to an engine exhausting into the atmosphere, as a "high-pressure engine," and to an engine exhausting into a condenser, as a "low-pressure engine." These two terms are very misleading, since, apparently, they refer to the steam pressure carried. To prevent any misunderstanding, the terms "condensing" and "non-condensing" engines are used in this Course.

In non-condensing engines, that is, engines which are not supplied with a condenser, the steam is exhausted into the atmosphere, and, therefore, the exhaust steam must have, at least, the pressure of the atmosphere; in practice, the back pressure of steam in a non-condensing engine is scarcely ever less than 16 pounds above vacuum, and is oftener 17 pounds or more. In good condensing engines the back pressure is often as low as 2 pounds above vacuum.

Suppose the boiler pressure is 80 pounds, absolute (above vacuum); the temperature corresponding to the pressure is, from the steam table, 311.9° F., and the absolute temperature is, therefore, $460° + 311.9° = 771.9°$ F. The absolute temperature corresponding to a pressure of 17 pounds is $460° + 219.5° = 679.5°$ F., and corresponding to a pressure of 3 pounds is $460° + 141.7° = 601.7°$ F. If then the engine is non-condensing and the steam exhausts at 17 lb. absolute, the thermal efficiency is $\frac{T_1 - T_2}{T_1} = \frac{771.9 - 679.5}{771.9} =$ 12%, nearly; if condensing, and the back pressure is 3 lb. absolute, the efficiency is $\frac{T_1 - T_2}{T_1} = \frac{771.9 - 601.7}{771.9} = 22\%$.

1084. The increase of economy by the use of the condenser may be shown in another manner. Let *A B C D E F*, Fig. 322, be an indicator diagram from a non-condensing engine. *M N* is the atmospheric line, and *O X* is the vacuum line. The back pressure, as shown by the diagram, is *O S*. The area of the diagram represents to some scale the work done per stroke. Now let a condenser be attached to the engine. The back pressure will be lowered to *O T*; the line *H K*, instead of *D E*, will now be the lower line of the diagram, and *A B C H K L* will be the new diagram,

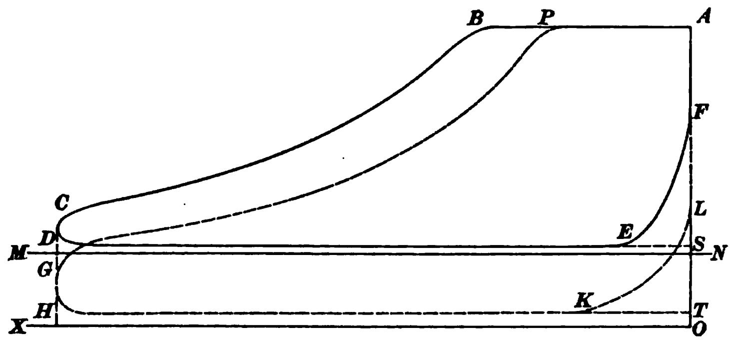


FIG. 322.

its area, as before, representing the work done per stroke. Hence, by adding a condenser to the engine, the work per stroke has been increased by an amount represented by the area *F E D H K L*, the steam consumption remaining the same. Suppose the steam to be cut off at a point *P*, making the area of the diagram *A P G H K L* equal to the area of the original diagram *A B C D E F*. Then, the work per stroke is the same in both engines, but the condensing engine uses an amount of steam per stroke represented by the length *A P*, while the non-condensing engine uses an amount represented by *A B*. Either case shows the economy of the condenser.

There are two types of condensers in general use: The **surface condenser** and the **jet condenser.**

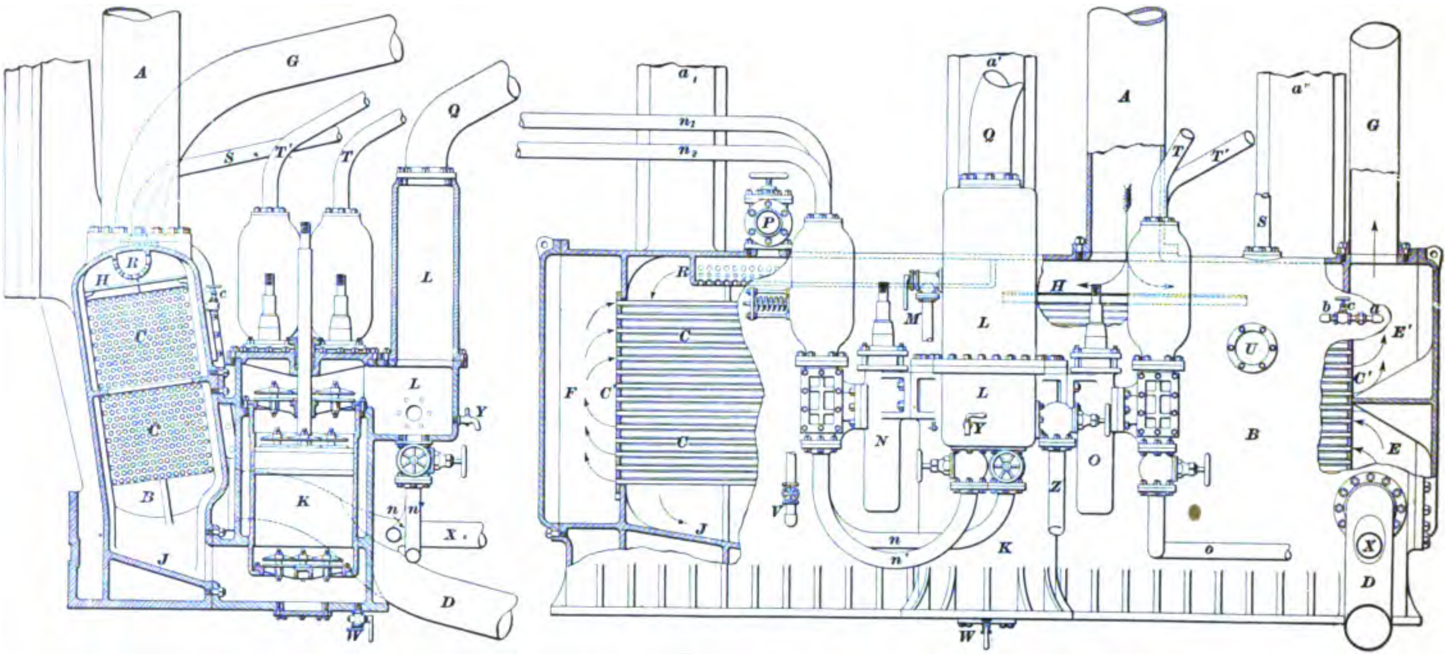


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FIG. 328.

THE SURFACE CONDENSER.

1085. In the surface condenser the exhaust steam comes in contact with a large area of metallic surface, which is kept cool by contact with cold water. In the jet condenser the exhaust steam on entering the condenser, comes in contact with a jet of cold water. In either case the entering steam is condensed to water, and, in consequence, a partial vacuum is formed. If a sufficient amount of cold water were used, the steam on entering would instantly condense, and were it not for the fact that the feed-water of the boiler always contains a small quantity of air which passes with the exhaust steam into the condenser, and, therefore, together with the vapor rising from the water of condensation, partially destroys the vacuum, a practically perfect vacuum would be obtained. To get rid of this air and vapor, the condenser is fitted with an air pump, which, in the case of a surface condenser, pumps out the air, vapor, and the water of condensation, i. e., the condensed steam, while, in the case of a jet condenser, it pumps out the air, vapor, and the mingled water of condensation and condensing water.

1086. In Fig. 323 a surface condenser of the form usually applied to vertical inverted screw-propeller engines is shown. It has been partially described in Art. **799.** This condenser, as is the usual practice, is provided with suitable connections to turn it into a jet condenser if necessary.

Assuming the circulating pump to have broken down at sea, and that it is not possible to run jet condensing, a temporary exhaust pipe would have to be rigged to carry the exhaust steam out of the engine room and on deck, in order to run the engine. But the necessity of doing this is obviated if the surface condenser can be readily turned into a jet condenser. Referring to Fig. 323, the pipe *P*, which is connected to a stop-valve attached to the condenser, either communicates with the sea or is connected to the delivery pipes of the auxiliary pumps, the latter plan being preferable.

The condensing water passes through the stop-valve into the perforated spray pipe *R* situated within the condenser; it mingles with the exhaust steam and condenses it. When running jet condensing, the air pump removes the mingled condensing water and water of condensation, and delivers it into the hotwell, from whence a part is taken by the feed-pumps, the rest passing overboard through the jet outboard delivery pipe *Q*. Before starting to run jet condensing, the delivery valve of the pipe *Q* must be blocked open, and the cock in the overflow pipe *M* closed. The delivery valve is, in effect, nothing but a check-valve bolted to the side of the vessel; it is applied to all pipes discharging water overboard through the skin of the vessel. Its construction will be shown further on.

Since sea-water is fed to the boilers when jet condensers are used, the condenser is converted into a jet condenser only in cases of emergency.

Since the boilers should be fed with fresh water, and since water from the hotwell of a surface condenser is always fresh, it is to-day the only condenser in use on sea-going steamers or fresh-water steamers carrying more than 40 pounds boiler pressure. The use of the jet condenser is at present confined, with a few exceptions, to fresh-water steam vessels carrying below 40 pounds boiler pressure. When dealing with the question of **Incrustation** (see Arts. **879-883**), it was shown that the sulphate of lime becomes insoluble and is precipitated at a temperature of 290° F. Hence, if the temperature corresponding to the steam pressure carried is kept below that point, no scale, or but very little, will be formed in the boiler; this showing that not more than 40 pounds boiler pressure should be carried when a jet condenser is used, if it is desired to prevent excessive incrustation and the attendant decrease of the efficiency of the boiler.

1087. In some instances no arrangements are provided to run jet condensing; it may often be done, however, by removing enough of the tubes to give an area of opening

equal to that of the main injection pipe D. If this is done, the delivery valve of the outboard delivery pipe G should be closed to prevent any air from entering the condenser. Frequently the auxiliary pumps can deliver into the water end through a pipe connection, as X, the pumps taking the place of the circulating pump in case of an accident to the latter. To allow examination of the inside, suitable manholes and handholes, one of which is shown at U, are provided. To drain the condenser, a drain cock W is fitted to the lowest part of it. Since the condenser tubes will in course of time be coated with grease carried in by the exhaust steam, the condenser will have to be boiled out occasionally. The condenser is nearly filled with water in which a quantity of caustic soda is dissolved; the water may be heated to the boiling point by live steam taken from the donkey boiler and admitted by the valve V. This valve may serve still another purpose. When running jet condensing, the air must be expelled from the condenser before the engine is started in order to be able to create a vacuum to assist the engine in starting. This refers to an engine in which the air pump is worked direct from the engine; that is, where the air pump can not act unless the engine is in motion. It will be readily seen that when the engine is standing, and the condenser is full of air, no vacuum can be formed. If the air is expelled, however, the admission of water through the jet injection will produce a vacuum sufficient, usually, to start the engine. Before starting, live steam is admitted to the condenser by the valve V, the steam driving out the air; the latter escapes through a so-called *snifting* valve attached to the steam end of the condenser. The **snifting valve** is simply a small check-valve attached to the condenser in such a manner that it is always kept closed by the pressure of the atmosphere. Hence, if live steam is admitted to the condenser, the pressure within the condenser will soon exceed the pressure of the atmosphere; the snifting valve then opens and allows the air and steam to escape. But as soon as a vacuum is formed, the valve closes and prevents the entrance of air. When no

snifting valve is fitted, the condenser drain cock W may be used instead; but since the latter is not automatic in its action, a man must be stationed there to open and close it when required. Since the valve V is used to blow steam through the condenser, it is often called the **blow-through** valve.

1088. Blow-through and snifting valves are always fitted to jet condensers used for marine work; they should also be fitted to surface condensers when the air pump and circulating pump are worked by the engine. If both pumps are independent of the engine, they are not so essential. The exhaust pipes from the different auxiliary engines are usually connected to one main exhaust pipe, as S, to allow them to be run condensing, thus saving fresh water. In the figure, a, a', and a'' represent the rear of the columns on which the cylinders are supported.

1089. The vacuum in the condenser is measured by means of a vacuum gauge, the construction of which is similar to that of a steam gauge. Instead of being graduated to read to pounds, however, it is graduated from 0 to 30 inches, a perfect vacuum representing about 30 inches of mercury. Since the pressure of the atmosphere is about 15 pounds to the square inch, every inch of vacuum represents about .5 pound pressure. Thus, if the vacuum gauge registers 26 inches, it means that $26 \div 2 = 13$ lb. of the atmospheric pressure have been removed from the exhaust side of the piston; or, in other words, that the back pressure is $15 - 13 = 2$ lb. per sq. in.

If greater accuracy is required in transforming inches of vacuum into pounds pressure, the pressure of the atmosphere must be taken at 14.7 pounds instead of 15 pounds. For instance, suppose it is required to transform a vacuum gauge reading of 24 inches into pounds pressure above vacuum. Since the difference between the reading of the gauge and a perfect vacuum is $30 - 24 = 6$ in., and since $14.7 \div 30 = .49$, the pressure above vacuum will be $6 \times 49 = 2.94$ lb. In all calculations in this Course and

in the examples pertaining to this subject the value .49 has been adopted. If the second decimal of the pressure found by using this value is, or exceeds, 5, one (1) may be added to the first decimal.

1090. It has previously been shown that the temperature of saturated steam depends entirely upon the pressure; hence, if the pressure within the condenser is known, the temperature of the condensed steam may be found from the steam table. Referring to this table, it will be seen that the less the pressure the lower the temperature. From this we may draw the conclusion, borne out by practice, that a high vacuum, i. e., a low pressure, means cold feed-water in the hotwell. Thus, if 28 inches of vacuum is carried, that is, 1 pound absolute pressure, the temperature of the condensed steam would be, from the steam table, about 102° F. However, if but 26 inches of vacuum is carried, the temperature would be 141.5°, nearly. It should be remembered that the temperature taken from the steam table is the maximum temperature of the water of condensation; this would be very nearly the temperature of the hotwell if just the proper amount of condensing water were used. Owing to practical difficulties it is not possible to feed the exact amount required, the amount fed being usually in excess of this. If just the proper amount of condensing water be supplied, the temperature of the water of condensation and of the discharged condensing water will be equal; the temperature of the hotwell will then be the highest that is possible for the vacuum carried. Hence, to have the water in the hotwell as hot as possible for the vacuum carried, the temperature of the discharged condensing water should be not more than 10 degrees lower than that of the water in the hotwell. If the condensing water is discharged within this range of temperature, the temperature of the hotwell will be about 15° F. below the theoretical temperature it should have. This loss in heat is partly due to the fact that rather too much condensing water is used, and also that some heat is lost by radiation. Thus, if a vacuum of 26 inches is carried,

the theoretical temperature in the hotwell would be about 141.5°, while the actual temperature will be found to be about $141.5 - 15 = 126.5°$. The temperature of the discharged condensing water would be about $126.5 - 10 = 116.5°$ F.

If a higher hotwell temperature is desired, a lower vacuum must be carried. This may readily be done by reducing the quantity of condensing water passing through the condenser.

The vacuum usually carried with surface condensers is from 24 to 26 inches; with jet condensers from 23 to 25 inches.

1091. A trouble frequently occurring is the bursting of one or more of the condenser tubes. If the vessel is running in salt water, it may be detected by tasting the water in the hotwell; it will be salty if there is any connection between the water end and the steam end. It may also be detected by the water gaining in the boilers, instead of gradually getting lower. To detect which tube or tubes are burst, the doors at the water end must be removed and the steam end filled with water through one of the manholes. Water will then issue from the split tubes, which may be temporarily repaired by driving in soft pine plugs at both ends.

CAUSES OF AN IMPERFECT VACUUM.

1092. An imperfect, i. e., a low, vacuum is due to one or more of three causes.

1. The amount of condensing water supplied may be insufficient.
2. The air pump may be out of order.
3. There may be air leaks.

1093. The probable cause may be ascertained if a *log* of the performance of the engine is kept. In this log the temperature of the hotwell, the temperature of the discharged condensing water, the temperature of the sea-water, and the vacuum carried are entered every hour. Should

the vacuum be found imperfect, the temperature of the hotwell and of the discharged condensing water should be ascertained. For this purpose a cock *Y* (see Fig. 323) is usually attached to the hotwell, and another cock, not shown in the figure, to the outboard delivery pipe *G*. If the temperature of both is found to be more than has been noted down in the log for a more perfect vacuum, it would tend to show that not sufficient condensing water is supplied. If an increased supply of condensing water fails to improve the vacuum, although it lowers the temperature of the hotwell and of the discharged condensing water, the indications are that an air leak exists somewhere about the condenser or engine. It may be found by passing a candle along the various joints; the flame of the candle will be drawn in wherever there is a leak. If no air leak is found, the air pump must be examined. Usually one of the valves in the bucket will be found hung up or broken. If the temperature of both the hotwell and the discharged condensing water are the same as in the case of a more perfect vacuum, it may be concluded that there is an air leak or a partially disabled air pump. To stop an air leak, apply a little red lead putty to the crack found.

When running jet condensing, the temperature of the hotwell and that of the condensing water are always the same, since the exhaust steam and condensing water mingle. Hence, the hotwell temperature remaining the same as in the case of a more perfect vacuum, either an air leak or an imperfectly working air pump would be indicated. If the hotwell temperature is greater it would indicate an insufficient quantity of injection water.

THE AIR PUMP.

1094. A common construction of an air pump is shown in Fig. 324. This is an enlarged view of the air pump shown attached to the condenser in Fig. 323. It consists of a cylindrical cast-iron casing *A*, lined with a brass barrel *B*; a piston, or bucket, *C* fits the barrel closely. The casing is bolted against the rear of the condenser in such a position that the

water of condensation will always flow into the pump. A number of foot-valves *b* and delivery valves *a*, four of each in this case, are fitted to the bottom and top ends of the pump barrel. Four similar valves *c* are fitted to the bucket. The operation of the pump is as follows: On the down stroke of the bucket, that is, when moving in the direction of the arrow *x*, the foot-valves and delivery valves are closed, and

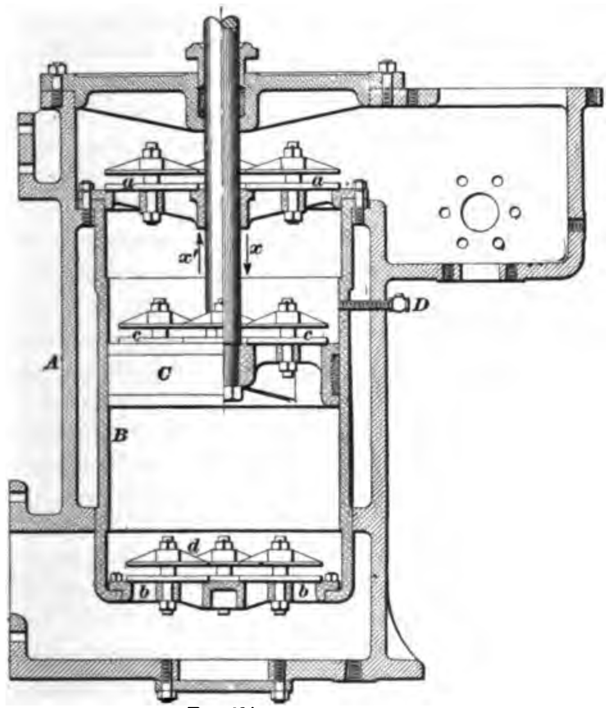


FIG. 384.

the bucket valves are opened. The water and air within the barrel above the foot-valves pass to the upper side of the bucket; and since the bucket valves close and the delivery valves open when the bucket moves in the direction of the arrow *x'*, the water and air are removed and thrown into the hotwell; at the same time a vacuum is formed below the bucket.

The delivery valves prevent the water and air in the

hotwell from passing back into the air pump. The foot-valves are not absolutely necessary; in fact, air pumps have sometimes been run for short periods without them. However, they serve to make the action of the pump more reliable, since they insure that the water drained from the condenser passes to the upper side of the bucket. All the valves are shown down on their seats, in the figure.

Vulcanite (hard rubber) valves are universally used for air pumps, in this country at least. They are circular flat plates seated on a flat brass seat. To confine and check their rise they are placed on a stud secured to the center of the valve seat. A brass guard *d* on the stud limits the rise of the valves. The valve seat is perforated to allow the water to pass. Usually a thin brass spring is placed between the guard and the valve, to assist the valve to return to its seat. These springs are usually fitted only to the bucket and delivery valves, but in some rare instances they will be found attached to the foot-valves. When placed there they may cause an imperfect vacuum. It is plain that if a spring is applied, more force is required to open the valves, and since the force acting to open the foot-valves is chiefly the hydrostatic head of the water of condensation, considerable water may accumulate within the condenser until the head is sufficient to overcome the resistance of the foot-valves. Since the air pump, instead of removing the water and air at every stroke, may then perform its duty but once every four or five strokes, an imperfect vacuum will result.

A small pet-cock, or better, a check-valve *D*, is usually attached to the pump below the delivery valve. Its purpose is to admit air on the down stroke of the bucket, the air cushioning the shock resulting from the water above the delivery valves being set in motion on the up stroke of the bucket. Whenever the air pump slams violently, it shows that either no air or not enough of it is admitted by the pet-cock; therefore, the remedy is to admit more air. The admission of air will affect the vacuum only in case the pump is working without the foot-valves, and then probably but very slightly.

Motion is imparted to the air pumps, feed-pumps, and bilge pumps by connecting them all to a common cross-head moved by a pair of levers, attached by links to the cross-head of the engine.

THE KEEL CONDENSER.

1095. This is a special style of surface condenser used only for small steam launches. It consists of a brass or copper tube placed outside of the vessel and along the keel. The engine exhausts into one end of the tube, and the steam is condensed by coming into contact with the cold surface of the tube; to the other end the air pump is attached. The principle of operation is the same as that of the condenser previously described. No circulating pump is used, however, since the condenser itself is submerged, and the water is circulated by the motion of the vessel. When starting the engine, in order to form a good vacuum, it is usually necessary to run the engine astern a few revolutions, thus projecting a stream of water over the condenser.

An example of a jet condenser will be given further on in connection with the beam engine.

QUANTITY OF WATER REQUIRED FOR CONDENSATION.

1096. The **water required by a condenser** may be calculated as follows:

Let t_1 = the temperature of departing condensing water;
t_2 = the temperature of entering condensing water;
t_3 = the temperature of the condensed steam upon leaving the condenser;
H = total heat of vaporization of one pound of steam at the pressure of the exhaust. This may be obtained from column 5 of the steam table;
W = number of pounds of water required to condense a pound of steam.

A pound of steam, after being condensed to water at a temperature of $t_3°$ contains $(t_3 - 32)$ more B. T. U. than a

pound of water at 32°. · But a pound of the original steam contains H units of heat more than a pound of water at 32°. Hence, the pound of steam in condensing to the temperature t_2° gives up $H - (t_2 - 32)$ B. T. U.

Each pound of water absorbs $(t_1 - t_2)$ B. T. U. in passing from the temperature t_2° to t_1°. (See rule **130,** Art. **667.**) It will, therefore, take $\dfrac{H - (t_2 - 32)}{t_1 - t_2}$ pounds of water per pound of steam; or,

$$W = \frac{H - t_2 + 32}{t_1 - t_2}.$$

Rule 185.—*To find the weight of condensing water per pound of steam, subtract the final temperature of the condensed steam from the total heat of a pound of the exhaust steam, and then add 32; divide the result by the difference between the temperatures of the entering and of the departing condensing water.*

EXAMPLE.—The steam exhausts into the condenser at a pressure of 4 pounds, absolute. The temperature of the condensing water on entering is 60°, and on leaving 100°. The temperature of the condensed steam on entering the air pump is 140°. How many pounds of condensing water are required per pound of steam?

SOLUTION.—From the steam table, the total heat of a pound of steam at 4 pounds pressure above vacuum is 1,128.641 B. T. U. Then, by rule **185,**

$$W = \frac{H - t_2 + 32}{t_1 - t_2} = \frac{1{,}128.641 - 140 + 32}{100 - 60} = 25.516 \text{ pounds. Ans.}$$

In the jet condenser the final temperatures of the cooling water and the condensed steam are the same; that is, $t_2 = t$

EXAMPLE.—Steam exhausts into a jet condenser at a pressure of two pounds above vacuum. The temperature of the condensing water is 60°, and the temperature of the mixture as it enters the pump is 135°. How much water must be used per pound of steam?

SOLUTION.—Applying rule **185,**

$$W = \frac{H - t_2 + 32}{t_1 - t_2} = \frac{1{,}120.462 - 135 + 32}{135 - 60} = 13.566 \text{ pounds. Ans.}$$

1097. The surface condenser is more generally used than the jet condenser, especially in marine practice. They cost more originally, and require more condensing water,

but they possess the great advantage of allowing only the condensed steam to return to the boiler; hence, any water, no matter how impure, may be used for condensing purposes. The jet condenser, on the other hand, pumps both condensing water and condensed steam into the hotwell, and, hence, if impure water be used, it will find its way into the boiler and form a scale.

COMPOUND AND MULTIPLE-EXPANSION ENGINES.

1098. No way has yet been found to lower the temperature of the exhaust steam below the temperature of the condenser, which varies from 125° to 160°. Consequently, the only available way to increase the amount of heat extracted from the steam by the engine is to raise the temperature and pressure of the entering steam. That is, in the fraction $\frac{T_1 - T_2}{T_1}$ the temperature T_2 is fixed at the temperature of the condenser, and can not be further decreased. Hence, the only resource is to increase T_1. Following out this idea, steam pressures have been steadily increased from 8 to 10 pounds (above atmosphere) in the time of Watt to 150 to 200 pounds per square inch, the pressures used in modern locomotives and marine engines.

Theoretically, it would be possible to make the efficiency of steam as high as we please by simply increasing indefinitely the pressure of the entering steam. Practically, this can not be done for two reasons: 1. The steam pressure is limited by the strength of the boiler. 2. Engine cylinders can not be made non-conductors of heat. When the temperature of the steam falls from T_1° to T_2°, the temperature of the cylinder walls falls through the same range. When the fresh steam from the boiler at temperature T_1 rushes into the cylinder, it comes in contact with the walls which have just been reduced to a temperature of T_2 by the outgoing exhaust. Consequently, a portion of the steam immediately condenses and gives up enough heat to reheat

the walls to $T_1°$. The steam thus condensed does no work, and is a dead loss. It is plain that by increasing the range of temperature $T_1 - T_2$, the loss due to cylinder condensation is largely increased.

1099. To see this clearly, let the pressure of the steam passing into the condenser be 4 pounds above vacuum; its temperature is about 153°. Let the pressure of the entering steam be say 60 pounds above vacuum; its temperature is about 293°. The fall in temperature is $293° - 153° = 140°$, nearly. Suppose, however, the entering steam had a pressure of 200 pounds above vacuum; its temperature would then be 382°, nearly, and the fall in temperature during the stroke would be $382° - 153° = 229°$. Now, it is plain that a great deal more of the incoming steam must condense to raise the temperature of the cylinder walls back from 153° to 382° than to raise them from 153° to 293°. *Hence, increasing the range of temperature increases the loss due to cylinder condensation.*

To obtain the advantages of a high pressure, and, at the same time, avoid the loss due to a cylinder condensation as much as possible, the steam may be allowed to expand successively in two or more cylinders. The fall of temperature is thus divided between the two or more cylinders, and, consequently, the loss from condensation in both, or all of them, is made considerably less than it would be if the same fall of temperature were allowed to take place in one cylinder. When the expansion takes place in two cylinders, the engine is said to be **compound**; if the expansion takes place successively in three cylinders, the engine is said to be **triple expansion**, and if in four cylinders, **quadruple expansion.**

It is important to note, however, that the expressions "compound," "triple," "quadruple" do not refer to the number of cylinders, but, rather, to the number of successive expansions the steam is subjected to. For example, take two engines, each with three cylinders, but arranged differently, as follows: In the first engine, suppose the steam

to, first of all, expand in the smallest of the three, then pass into the next largest and expand there, and, finally, undergo a third expansion in the largest cylinder. This engine is a *triple-expansion* engine, because the steam has had three separate expansions. In the other case, however, the steam after expanding in the smallest cylinder may divide, each half expanding in one of the other cylinders. Hence, the steam undergoes but two separate expansions, and the engine is a *compound*, though it has three cylinders. Similarly, a triple engine may have four or even five cylinders.

1100. Compound engines are usually made in one or the other of the two types shown in Fig. 325. In (*a*) the

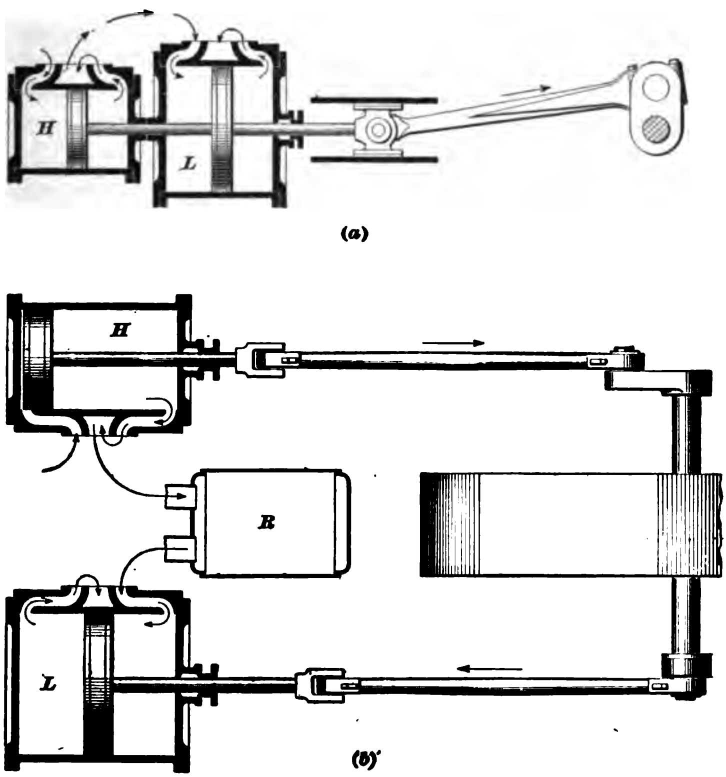


FIG. 325.

two cylinders are placed in line, the two pistons being attached to the same piston rod. *H* is the cylinder which first receives steam from the boiler; it is called the **high-pressure** cylinder. After the steam has expanded in *H*, it passes to the larger cylinder *L*, which is called the **low-pressure** cylinder; from here the steam is exhausted into the atmosphere or into a condenser. Fig. 325 (*b*) shows what is known as the **receiver-compound** engine. The steam enters the high-pressure cylinder *H* from the boiler; exhausts into a separate vessel *R*, called the **receiver**; from there it passes to the low-pressure cylinder *L*, and finally exhausts into the atmosphere or into a condenser.

1101. A receiver-compound engine has two piston rods and two cranks; the cranks may be placed at any angle with each other. The compound engine without a receiver may have one piston rod and crank, as shown in the tandem type, or it may have two piston rods and two cranks, the cylinders being placed side by side. In any compound engine, without a receiver, the two pistons must begin and end their stroke at the same time, and the two cranks must be together or placed 180° apart.

When one cylinder is placed behind or above the other, as shown at (*a*), Fig. 325, the engine is called a **steeple compound,** in the case of a vertical engine, and a **tandem compound,** in case of a horizontal engine. When the cylinders are placed side by side as shown at (*b*), and the piston rods are attached to separate cross-heads, the engine is called a **fore-and-aft compound.** If any of these types of engines have a condenser, they are called **steeple,** or **fore-and-aft compound condensing engines.** Without a condenser, they are called **non-condensing engines.** Marine engines, with the exception of the steeple-compound type, usually have receivers.

1102. In giving the size of a multiple-expansion engine, the stroke is always written last. Thus, a compound engine whose high-pressure cylinder is 11″ in diameter, low-pressure cylinder 20″ in diameter, and stroke 15″, would be expressed

as a 11″ and 20″ × 15″ compound. In the same manner, a 14″, 22″, and 34″ × 18″ triple-expansion engine, would indicate that the diameters of the cylinders were 14″, 22″, and 34″, and that they had a common stroke of 18″. A three-cylinder compound having a 11″ high-pressure cylinder and two 14″ low-pressure cylinders, with a common stroke of 15″, would be expressed as 11″, 14″, and 14″ × 15″ compound engine.

1103. The **ratio of expansion** of a compound or triple-expansion engine is the ratio between the volume of steam exhausted into the atmosphere or the condenser per stroke and the volume of steam in the high-pressure cylinder at the point of cut-off.

Let e = ratio of expansion in high pressure cylinder;
E = total ratio of expansion;
v = volume of cylinder receiving steam from the boiler;
V = volume of cylinder exhausting into atmosphere or condenser.

Then, $$E = \frac{e\,V}{v}.$$

Rule 186.—*The total ratio of expansion, or as it is usually expressed, the number of expansions, is equal to the ratio of expansion of the small cylinder multiplied by the ratio between the volumes of the low and high-pressure cylinders.*

EXAMPLE.—In a compound engine the volume of the low-pressure cylinder is 3.2 times that of the high-pressure cylinder, and the number of expansions in the latter is 2.4. What is the total ratio of expansion?

SOLUTION.—According to rule **186**,

$$E = \frac{e\,V}{v};\ \text{now, } e = 2.4 \text{ and } \frac{V}{v} = 3.2.$$

Hence, $E = 2.4 \times 3.2 = 7.68$. Ans.

The total ratio of expansion varies from 6 to 12 for compound engines and from 10 to 25 for triple-expansion engines.

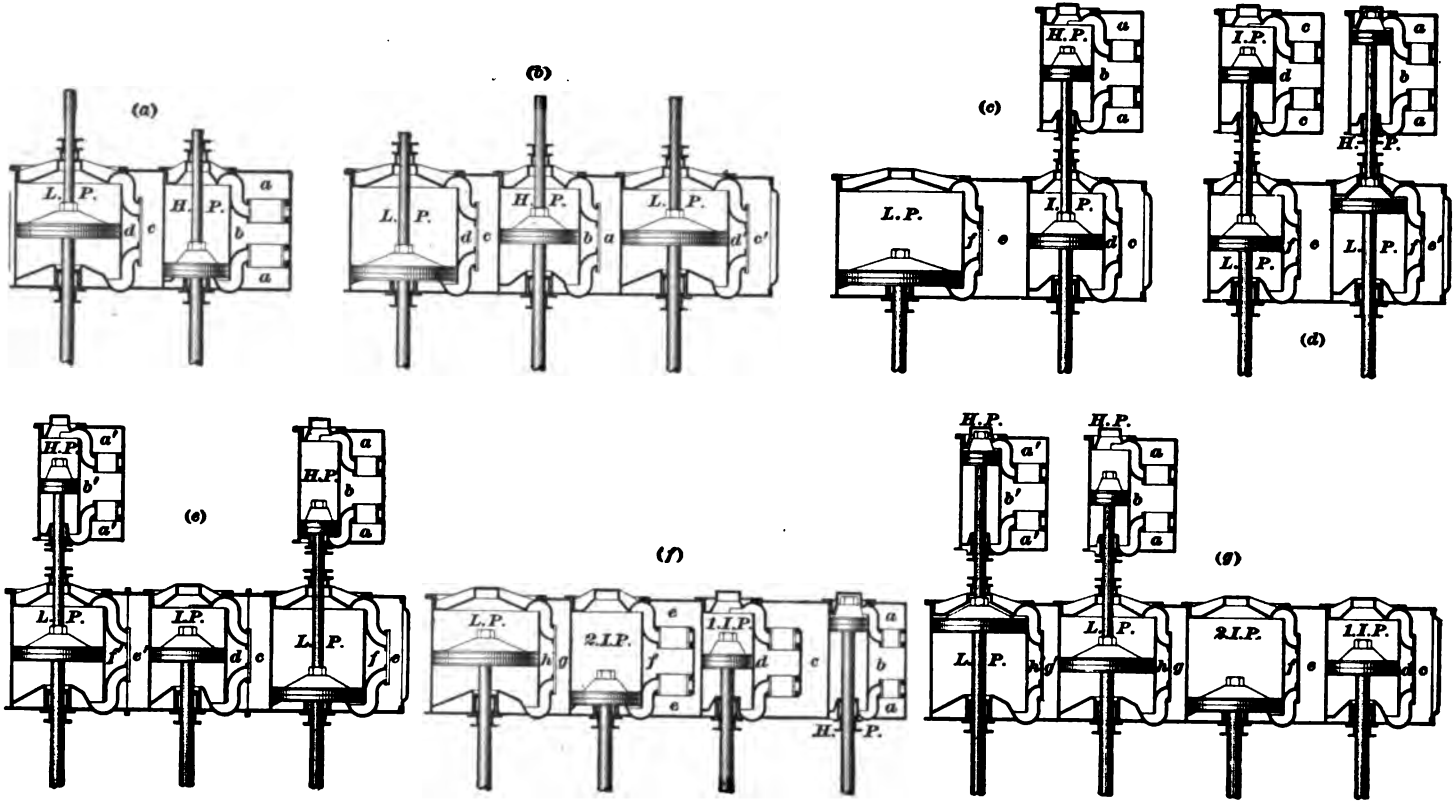


FIG. 326.

EXAMPLES OF COMPOUND ENGINES.

1104. It is customary to designate the cylinders and other component parts of compound and multiple-expansion engines as follows:

H. P. = high-pressure cylinder;
I. P. = intermediate-pressure cylinder;
1. I. P. = first intermediate-pressure cylinder;
2. I. P. = second intermediate-pressure cylinder;
L. P. = low-pressure cylinder.

In the description of the various cylinder arrangements, these designations have been adopted, and in Fig. 326, the cylinders have been lettered to correspond. In English books, M. P. designates the intermediate-pressure cylinder.

The most common forms of compound, triple, and quadruple expansion engines are illustrated in diagrammatic form in Fig. 326.

1105. At (*a*), Fig. 326, the cylinders of a fore-and-aft compound engine are shown. The cranks are placed 90° apart. Steam from the boiler enters the high-pressure steam chest *a*; after doing its work in the H. P. cylinder, it exhausts through *b* into the receiver *c*; thence it passes into the L. P. cylinder, and exhausts through *d* into the condenser.

1106. (*b*), Fig. 326, shows the cylinders of a three-crank, three-cylinder, fore-and-aft compound engine. In this, as is the usual practice in three-crank engines, the cranks are placed 120° apart. Steam from the boiler enters the H. P. cylinder from the steam chest *a*; the steam is exhausted through *b* into the receiver *c c'*, common to both L. P. cylinders. The L. P. cylinders exhaust through *d* and *d'* into the condenser. In case the engine is very large, there may be two condensers fitted; each L. P. cylinder then exhausts into its own condenser.

1107. The arrangement of the cylinders of a two-crank, three-cylinder, triple-expansion engine is shown at (*c*), Fig. 326. The cranks are placed 90° apart. Steam enters the H. P. cylinder from the steam chest *a*; it exhausts through

b into the steam chest *c* of the I. P. cylinder; the latter exhausts through *d* into the low-pressure receiver *e*. The exhaust port *f* communicates with the condenser. It will be noticed that no receiver is fitted between the H. P. and I. P. cylinders. This design is chiefly used in converting two-crank compound engines into triple-expansion engines.

1108. (*d*), Fig. 326, shows the cylinder arrangement of a two-crank, four-cylinder, triple-expansion engine. Steam enters the H. P. cylinder from the steam chest *a*; it exhausts through *b* into the intermediate receiver *c*, whence it passes into the I. P. cylinder. The latter exhausts through *d* into the low-pressure receiver *e e'*, common to both L. P. cylinders. Through *f* and *f'* the exhaust steam from the L. P. cylinders passes into the condenser. The cranks are placed 90° apart.

1109. The cylinder arrangement of a three-crank, five-cylinder, triple-expansion engine is shown at (*e*), Fig. 326. The cranks are placed 120° apart. There are two H. P. and two L. P. cylinders, and one I. P. cylinder. Steam from the boilers is led to the steam chests *a*, *a'* of the two H. P. cylinders; both exhaust, through their respective passages *b* and *b'*, into the intermediate receiver *c*. After performing its work in the I. P. cylinder, the steam exhausts through *d* into the low pressure receiver *e e'*, common to both L. P. cylinders. The passages *f*, *f'* communicate with the condenser or condensers.

1110. (*f*), Fig. 326, illustrates the cylinder arrangement of a four-crank, four-cylinder, quadruple-expansion engine. Steam enters the H. P. cylinder from the steam chest *a*; it exhausts through *b* into the first intermediate receiver *c*, whence it passes into the 1. I. P. cylinder. The exhaust from the latter passes through *d* into the second intermediate receiver *e*, and thence into the 2. I. P. cylinder. This cylinder exhausts through *f* into the low-pressure receiver *g*, whence the steam passes into the L. P. cylinder and exhausts through *h* into the condenser. The cranks are placed 90° apart.

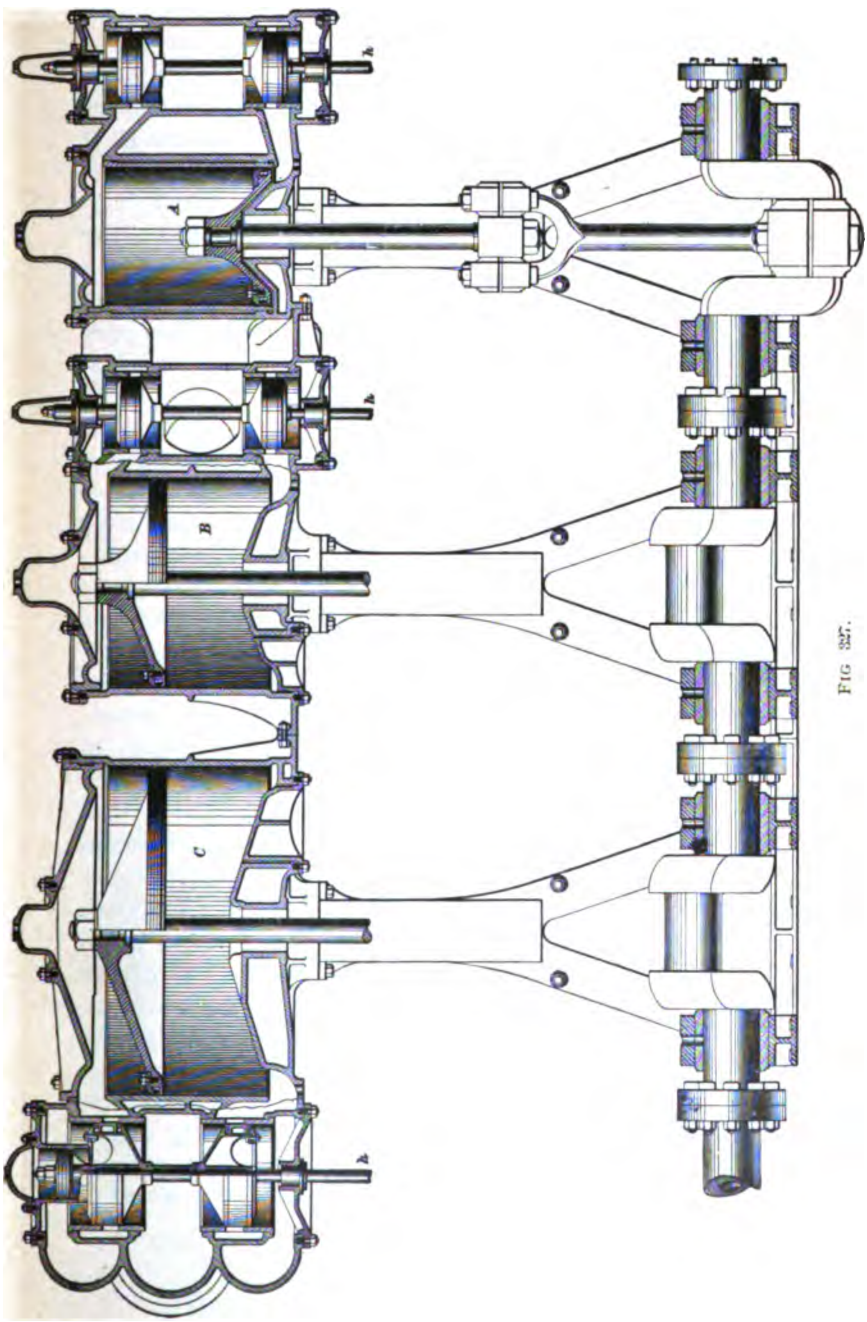


FIG 327.

1111. The cylinders of a four-crank, six-cylinder quadruple-expansion engine are shown at (*g*), Fig. 326. This arrangement is adopted for the engines of the steamships "St. Louis" and "St. Paul." The cranks are 90° apart. There are two H. P. and two L. P. cylinders, with the H. P. cylinders placed above the L. P. cylinders. Steam from the boilers is admitted to the valve chests *a* and *a'*. Both H. P. cylinders exhaust through their respective passages *b* and *b'* into the first intermediate receiver *c*. The 1. I. P. cylinder exhausts through *d* into the second intermediate receiver *e*. The 2. I. P. cylinder exhausts through *f* into the low-pressure receiver *g g'*, common to both L. P. cylinders. The passages *h*, *h'* connect with the condenser.

1112. Fig. 327 shows a section of a triple-expansion marine engine of the type usually fitted on board of naval vessels. The arrangement of the cylinders is the one most commonly employed for three-crank, three-cylinder, triple-expansion engines. Marine engines are nearly always of the vertical type, since a vertical engine occupies much less floor space than a horizontal engine of the same capacity. *A* is the high pressure; *B*, the intermediate, and *C*, the low-pressure cylinder. The cranks are placed 120° apart; hence, when the piston in *A* is beginning its stroke, the pistons in *B* and *C* are on the same level, but moving in opposite directions, one having traveled $\frac{3}{4}$ and the other $\frac{1}{4}$ of its stroke. The steam exhausts from *A* into *B*; from *B* into *C*, and from *C* into the condenser. The valves (not shown in their proper positions) consist of pistons connected by a rod. They are moved by means of the stems *h*, which are connected to eccentrics on the crank-shaft in the usual manner. A glance at the cut will show that these valves are perfectly balanced. The valves shown in the figure are examples of *direct* piston valves, that is, they admit steam past their outer edges. Their operation is exactly the same as that of the common slide valve. The crank-shaft is made considerably larger than necessary for strength in order to obtain a greater bearing surface, and thus reduce the amount of wear

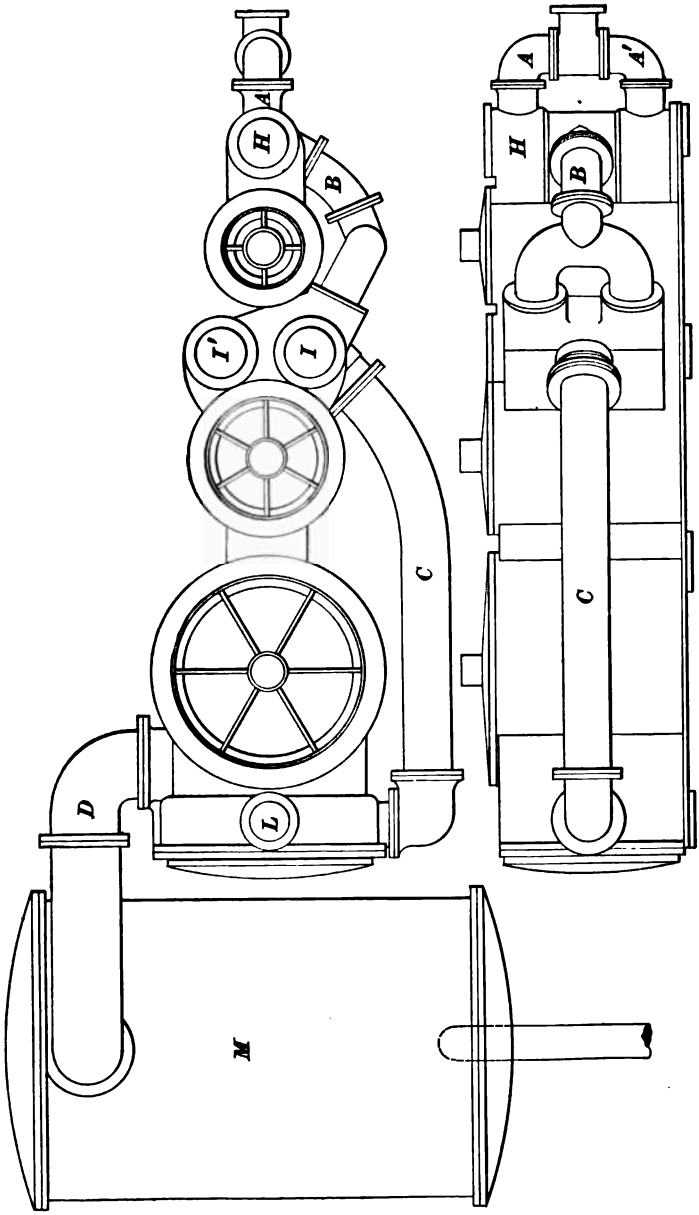


FIG. 328.

due to friction. It is also made hollow to reduce the weight.

The route of the steam through a triple-expansion engine may be more clearly seen in Fig. 328, which represents a plan and elevation of the cylinders of a marine engine (not the one of Fig. 327).

Steam from the boiler enters the two ends of the high-pressure steam chest *H*, through the pipe *A A'*. It is exhausted from the center of the steam chest through *B* to the two ends of the intermediate steam chest *I I'*. After expanding in the intermediate cylinder, it exhausts from the middle of *I* through the pipe *C* into the low-pressure steam chest *L*; and finally from *L* through the pipe *D* into the condenser *M*. After condensing in *M*, the steam, in the form of water, is pumped out of the condenser into the hot-well, and from there into the boiler.

It may be observed that the steam chest *I* has two piston valves. In large triple-expansion engines, each cylinder may have two, or even more, piston valves.

1113. Triple and quadruple expansion-engines are sometimes constructed in such a manner that they may be run as compound engines.

Referring to Fig. 328, assume that a branch pipe is fitted to the pipe *C*, the branch pipe connecting with the condenser. Further assume that a stop-valve is placed on the branch pipe, and that another stop-valve is placed on the pipe *C*, between the points where *C* enters the low-pressure cylinder and where the branch pipe connects to *C*. Then, if the stop-valve in *C* be closed and the stop-valve in the branch pipe be opened, the I. P. cylinder would exhaust into the condenser; i. e., the engine is now a compound. When running as a compound engine, the steam pressure is lowered.

The usual steam pressures (gauge) carried are as follows:

Single-cylinder engines	Up to 60 lb.
Compound engines	60 to 120 lb.
Triple-expansion engines	120 to 180 lb.
Quadruple-expansion engines	160 to 220 lb.

The receivers may be formed by enclosing the space between the cylinders, or they may be formed by the pipes conveying the exhaust steam of one cylinder to the next, as shown in Fig. 328. In either case the receiver simply forms a reservoir for steam.

HORSEPOWER OF COMPOUND ENGINES.

1114. The actual I. H. P. of a compound or triple-expansion engine may be obtained from the indicator diagrams. The method used is best shown by an example.

EXAMPLE.—A triple-expansion engine has the volume of its cylinders in the ratio 1 : $2\frac{1}{2}$: $6\frac{1}{4}$; that is, the low-pressure cylinder is $6\frac{1}{4}$ times as large as the high-pressure cylinder and $\frac{6\frac{1}{4}}{2\frac{1}{2}} = 2\frac{1}{2}$ times as large as the intermediate cylinder. The low-pressure cylinder is 40" × 40". The engine makes 120 revolutions per minute. On measuring the actual diagrams it is found that the M. E. P. of the high-pressure cylinder is 80.5 pounds; the M. E. P. of the intermediate cylinder, 37.5 pounds, and of the low-pressure cylinder, 16.12 pounds. What is the I. H. P. of the engine?

SOLUTION.—It would be possible to calculate the I. H. P. by finding the work done by each cylinder separately, as if it were the cylinder of a simple engine, and then adding the amounts (of work) together. It is easier, however, to reduce all the pressures to the area of the low-pressure cylinder. This is done by dividing the M. E. P. of each cylinder by the ratio between its volume and the volume of the low-pressure cylinder. In the present case the M. E. P. of the high-pressure cylinder is 80.5. The volume of the low-pressure cylinder is 6.25 times that of the high-pressure cylinder, or, what is the same thing, the area of the low-pressure piston is $6\frac{1}{4}$ times that of the high-pressure piston. Therefore, to perform the same work, the M. E. P., when acting in the low-pressure cylinder, must be $\frac{1}{6.25}$ of what it was in the high-pressure cylinder. The M. E. P. of the small cylinder, reduced to the area of the low-pressure cylinder, is, therefore, $\frac{80.5}{6.25} = 12.88$ lb. Likewise, the M. E. P. of the intermediate, reduced to the low-pressure cylinder, is $\frac{37.5}{2.5} = 15$ lb. The M. E. P. of the low-pressure cylinder, of course, remains the same. The total M. E. P., reduced to the low-pressure cylinder, is, therefore, $12.88 + 15 + 16.12 = 44$ lb.

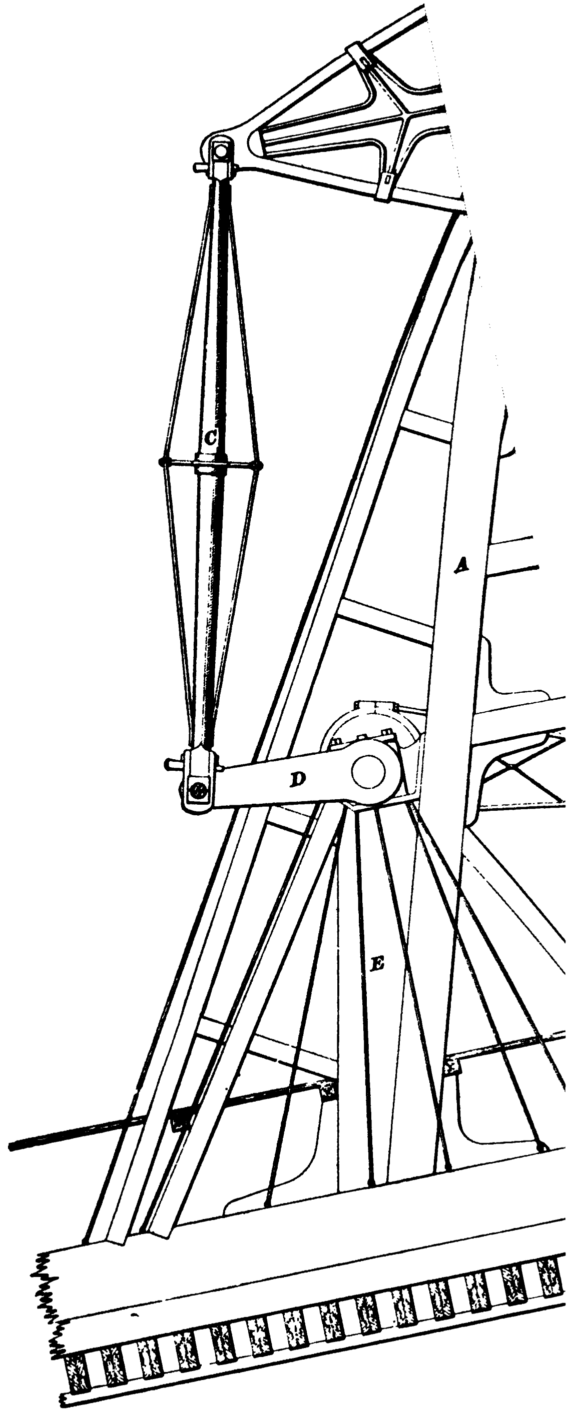
Now, substituting this M. E. P., the area of the low-pressure cylinder, the length of stroke, and revolutions per minute in rule 180,

$$\text{I. H. P.} = \frac{P L A N}{33{,}000} = \frac{44 \times 40 \times 40^2 \times .7854 \times 120 \times 2}{12 \times 33{,}000} = 1{,}340.42. \quad \text{Ans.}$$

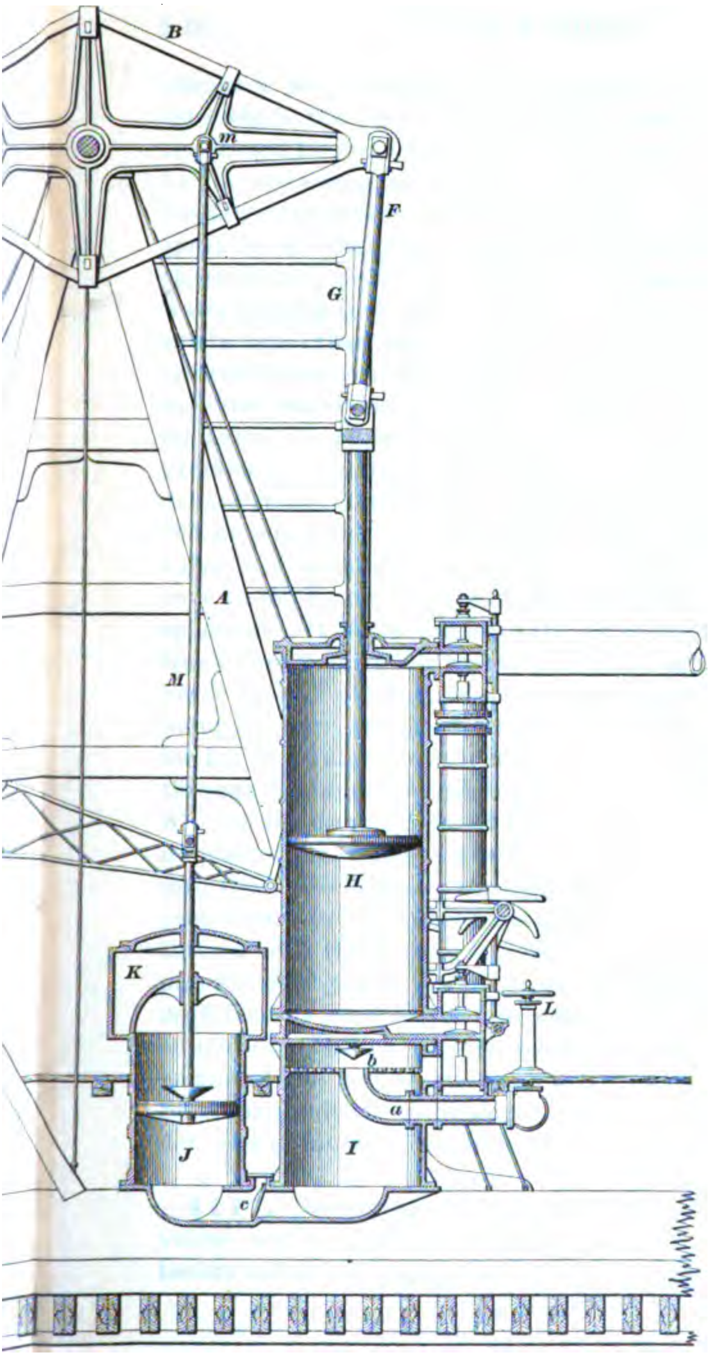
1115. If the engine is of the type in which the air pump, feed-pumps, etc., are driven directly by the engine, the horsepower of the engine driving the pumps is usually made large enough to equal the power required to drive the pumps plus the power of the other engine. This is done in order that each engine may apply the same force to the turning of the propeller. When all pumps are independent of the engine, the aim is to make each cylinder develop the same power.

THE BEAM ENGINE.

1116. This type of engine is still extensively used for paddle-wheel river steamers. It has undergone but very slight changes during the last forty years. The usual design of such an engine is shown in Fig. 329. In the figure, *A*, *A* are the legs of the **gallows frame,** which carries on top the bearings for the **walking beam** *B*. The latter is made with a cast-iron center surrounded by a wrought-iron strap. At one extremity of the walking beam the connecting-rod *C* is attached; the latter converts the vibrating motion of the walking beam into rotary motion through the medium of the crank *D* keyed to the paddle-wheel shafts. The inboard shaft bearings are bolted against the frame; their weight, as also that of the shafts, is taken by the strut *E*. The whole frame of the engine is made of wood; it is well braced, fore and aft, as well as athwartship, by struts and iron tension rods. The cylinder *H*, which is provided with a piston and piston rod, is placed below the other extremity of the walking beam. The end of the piston rod carries a cross-head, which is connected to the walking beam by means of the link *F*. Guides *G*, which serve to carry the cross-head in a straight line, are bolted to the top of the cylinder, and steadied by struts attached to the frame. The condenser *I* is placed underneath the cylinder. The condenser is nearly



C
A
D
E



'IG. 329.

always a jet condenser. It is simply a cylindrical vessel, into which the steam is exhausted; the exhaust steam is condensed by mixing with the cold injection water admitted by the main injection pipe *a*. In order to more effectually condense the steam, the injection water is broken up into a spray by a cone-shaped projection *b* placed directly above the injection pipe. To regulate the amount of injection water passing into the condenser, a valve *L*, known as the **main injection** valve, is fitted to the injection pipe. Since the condenser is always placed low down in the vessel, the injection water runs into the condenser by gravity. The air pump *J* is placed forward of the condenser; as previously explained, it removes the mingled injection water and condensed steam, and assists in maintaining a vacuum. At *c* the air pump foot-valve is shown. The air pump delivery valve is of peculiar construction. As will be seen by reference to the figure, the top of the air pump is made hemispherical. It is not bolted to the air pump, however, but is free to move vertically on the piston rod of the pump. The lower face of the top, as well as the upper face of the air-pump cylinder, are faced carefully. On the up stroke of the bucket, the water above it lifts the cover, the water escaping through the annular opening thus formed, into the hotwell *K*. On the down stroke of the bucket, the cover returns to its place, thus acting as a delivery valve. The water thrown into the hotwell passes through the outboard delivery pipe (not shown in the figure) overboard. Some of the water thrown into the hotwell is used for feeding the boilers. A plunger feed-pump worked from the walking beam may be used for this purpose; or independent steam pumps may be employed. Motion is imparted to the air-pump bucket by means of the rod *M* attached to the walking beam at *m*. Steam is admitted to the upper and lower ends of the cylinder, and exhausted therefrom by four independent valves.

1117. Referring to Fig. 330, *U* and *V* are the steam valves, and *U'* and *V'*, the exhaust valves. Steam from the boilers enters the upper valve chest through the steam pipe

A ; it is conducted to the lower valve chest by the **side pipe** *C*. When the valve *V* is raised, steam passes through the annular openings between the valve and its seats into the steam port *B*. When the exhaust valve *V'* is raised, the exhaust steam passes down the side pipe *C'* and through the opening *D* into the condenser. To separate the steam and exhaust parts of the valve chests, they are divided by a partition *a a*. The side pipes are bolted to the bottom valve chest; they are attached to the upper one, however, by means of expansion joints in order to allow the side pipes to expand freely.

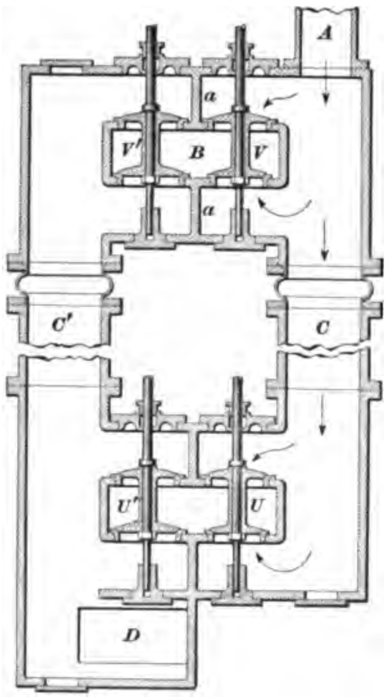


FIG. 330.

1118. The Double-Seat Poppet Valve.—The steam and exhaust valves of beam engines are invariably of this type. Referring to Fig. 330, it will be seen that the valve *V* consists of two disks connected together by a sleeve. This valve stem passes through the valve, the valve being secured to the stem by a nut on the bottom and a collar on top. At its lower extremity, the stem is guided by a dummy gland, central with the valve seats, and bored to fit the stem. At the upper extremity, the stem is guided by the stuffing-box and gland. With the valve in the position shown, i. e., seated, all communication between the valve chest and the steam port *B* is shut off. It will be noticed that the steam surrounds the valve. Hence, if both disks had the same diameter, the valve would be exactly in

equilibrium; that is, no force but that required to overcome the weight of the valve, and the friction of the valve stem would be needed to raise it. This is due to the fact that the upward pressure on the lower disk just balances the downward pressure on the upper disk. But since it is desirable to have some pressure on top in order to hold the valve down when seated, the diameter of the upper disk is made slightly larger than that of the lower one. The diameter of the latter is usually made such that it will slip through the upper valve seat. Then, the difference in the areas of the two disks multiplied by the steam pressure will be the force holding the valve to its seat; hence, that force plus the weight plus the friction must be overcome in raising the valve. The double-seat poppet valve is a great improvement over the single-seat poppet valve formerly used. The latter is simply a single disk with the steam pressure on top of it. The improvement of the former valve over the latter may best be shown by a calculation. Thus, if a single-seat poppet valve 8 inches in diameter, weighing 30 pounds, is subjected to a steam pressure of 40 pounds, the force required to lift the valve is $8^2 \times .7854 \times 40 + 30 = 2{,}040.62$ lb. Suppose a double-seat poppet valve is substituted, the diameter of the larger disk being 8 inches, and of the smaller disk 7.5 inches. Let its weight be 50 pounds, and the steam pressure the same as above. Then, the force required to lift the valve is $(8^2 \times .7854 - 7.5^2 \times .7854) \times 40 + 50 = 293.48$ lb. Thus, it is seen that the power required to lift the valve is enormously reduced. Another advantage of the double-seat poppet valve is that it needs to be raised only about one-half as high as a single-seat valve of the same diameter in order to give the same effective area. From this it follows that for an equal lift, the double-seat poppet valve may be considerably smaller, and still allow the same quantity of steam to pass through it.

In order that the steam valves may be held to their seats, the diameter of the upper disk is always made the larger. In the exhaust valves, however, the lower disk is made the larger. Then, since the pressure within the cylinder exceeds

the pressure in the condenser, when the exhaust valves are closed, the internal pressure will hold the valves down. In order that the exhaust valves may be placed in position, they are made in two parts held together by the valve stem and its locknut. The upper valve seat is usually made removable, and the hole in the valve chest into which it is fitted is made large enough to allow the lower disk to pass through. In some cases, however, the lower disk has to be passed through the steam port to enable the valve to be put in position.

BEAM-ENGINE VALVE GEARS.

1119. The **Stevens' adjustable cut-off** valve gear, illustrated in Figs. 331 and 332, is perhaps the one most commonly used. In order to show the valve gear clearly, the cylinder, valve chests, guides for the lifter rods, etc., have been omitted in the figure.

There are four double-seat poppet valves A, A' being the steam valves, and B, B' the exhaust valves. The valves are raised by four lifter rods, a, b, c, d—one for each valve. Four toes are attached to the lifter rods, a', b' being the exhaust toes, and c', d' the steam toes. The lifter rods are attached to the valve stems by means of the brackets e, f, g, h. In order to allow for any inaccuracies of workmanship, etc., the hole in the bracket through which the valve stem passes is made somewhat larger than the stem. The valve stem is confined vertically by locknuts adjusted so as to permit a lateral movement of the stem without any lost motion vertically. There are two rocker shafts, one for the steam valves, and one for the exhaust valves. In addition to the end bearings, the two rockers have a common bearing (omitted in the figure) between the lifter rods b and c. Wipers a_1, b_1, c_1, d_1 are attached to the rocker shafts by means of set-screws; they are placed directly beneath the toes. Each rocker shaft is worked by its own eccentric, and the eccentrics are placed one on each side of the crank. The exhaust wipers are so adjusted with reference to the toes that the moment one valve is fairly seated the other one

commences to lift. The steam wipers, however, are so adjusted that there is an interval between the seating of one valve and the lifting of the other. During the time both valves are seated the steam expands in the cylinder.

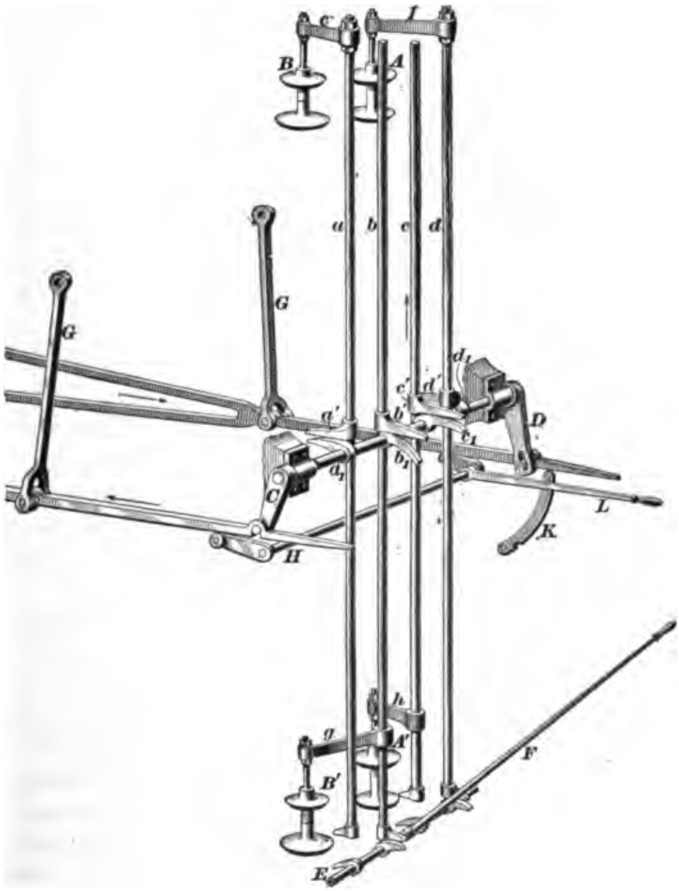


FIG. 331.

The eccentric-rods are not fastened to the rocker-arms, but are hooked over a pin carried in the ends of the latter. The pin in the exhaust rocker-arm *C* is fixed; the end of the steam rocker-arm is slotted to allow *its* pin to move up or down; it may be locked in position by means of a locknut.

1120. When working the engine by bell signals, as for instance, going in or out of dock, the steam is distributed by hand. For this purpose a trip shaft *E*, which carries steam and exhaust wipers engaging toes on the lifter rods, is placed beneath the latter. Motion is given to the trip shaft by means of the starting bar *F*, which is alternately raised and depressed by the engineer, thus rocking the trip shaft to and fro, and raising and seating the valves. The direction in which the crank will turn is determined by the motion of the starting bar. For instance, assume the engine to be standing and the piston at half stroke. Then, with the crank in the position shown in Fig. 329, and the upper steam valve opened, the crank will move upwards and turn to the right. But if the lower steam valve is opened, the crank will move downwards and turn to the left. Again, with the crank just opposite the position shown in Fig. 329 and the upper steam valve opened, the crank will move upwards, but turn to the left. When working the engine with the starting bar, the eccentric-rods are unhooked from the rocker-arms. To facilitate the latter operation, each eccentric-rod is divided into two parts (see Fig. 331); the heavier parts are supported by the swinging links *G*, *G* hung from brackets bolted to the cylinder. The two parts of the eccentric-rods are hinged together; the short ends may be detached from the rocker-arms by means of crank arms carrying rollers, and keyed to the tumbling shaft *H*. The eccentric-rods travel on the rollers while the engine is worked by the starting bar. To move and to hold the tumbling shaft in position, a lever *L* and notched quadrant *K* are employed. The starting bar is removed from its socket in the trip shaft when the valves are placed under control of the eccentrics.

1121. The valve gear is shown in diagrammatic form in Fig. 332. With the crank *A B* in the position shown, that is, on the top center, the piston is at the bottom and just about to move upwards; hence, the lower steam valve has just opened. With the crank moving in the direction of

the arrow x, the eccentric $A\ C$ moves the rocker-arm $E\ D$ to the right; hence, the wiper G engages the toe H and moves the lifter rod F upwards, thus opening the lower steam valve still further. But when the crank has moved far enough for the eccentric to occupy the position $A\ C'$,

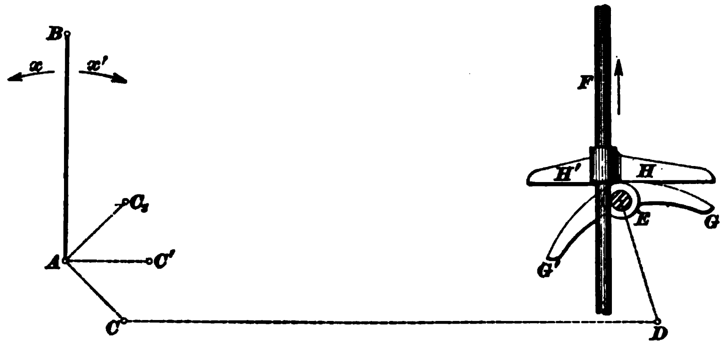


FIG. 332.

the motion of the rocker-arm is reversed; that is, it moves to the left and the valve gradually seats. Owing to lack of space, the eccentric-rod $C\ D$ is shown considerably shorter than it is in reality.

When fully seated, the wiper G moves away from the toe H; the wiper G' moves upwards but does not engage the toe H' on the upper steam valve lifter rod until the crank is very near the bottom center, the interval being the time during which the steam expands. In order to make the engine reversible, the eccentric is free to slip around the shaft until it occupies the position $A\ C_1$, when its further motion is arrested by a stop on the shaft. Then, with the crank on the top center, and moving in the direction of the arrow x', the rocker-arm is moved to the right, the wiper G engages the toe H, and the lower steam valve is opened, as required. The exhaust eccentric is also free to move around the shaft, and effects the opening and closing of the exhaust valves in a similar manner.

In later forms of this valve gear, four eccentrics are employed, two for the steam valves and two for the exhaust valves. The steam eccentrics are fastened to the shaft in

the positions $A\ C$ and $A\ C_1$, one serving for going ahead and the other for backing. The exhaust eccentrics are fastened in their relative positions for the same purpose. The pins in the rocker-arms are made long enough for either eccentric-rod to be hooked over them. When running in either motion, the eccentric-rods for that motion are hooked in, and the two rods for the other motion are lifted out of the way.

When a beam engine is to be reversed, the eccentric-rods must be disengaged first; the engine is then started in the required direction by tripping the valves with the starting bar; after which, with shifting eccentrics, the rods are hooked over the rocker-arm pins. If four eccentrics are employed, the eccentric-rods for the motion the engine is in are attached to the pins.

If the cut-off is to take place earlier, it may be done as follows: First the eccentric $A\ C$, Fig. 332, is shifted around the shaft nearer to the position $A\ C'$. Then, the distance moved by the crank, and, hence, the piston, is less than before, at the instant the rocker-shaft reverses its motion; hence, since the valve will seat in the same length of time it took to raise it, it will seat earlier than before; that is, cut-off takes place earlier. But in order that the valves may lift at the proper time, the steam wipers G and G' must both be lowered. To give the valve the same lift as before, the pin in the rocker-arm must be shifted upwards, thus shortening the rocker-arm. If the cut-off is to take place later, the eccentric is moved away from the position $A\ C'$, the steam wipers are raised, and the pin in the rocker-arm lowered. Since it is hardly ever necessary to change the working of the exhaust valves, no provision is made for doing so. With the Stevens' cut-off gear, owing to the multiplicity of operations, the cut-off can not be changed very readily while the engine is in motion.

1122. Setting the Valves.—The first step is to ascertain the proper length of the eccentric-rods. This, together with the succeeding operations, is the same both for the

steam and exhaust valves; therefore, the setting of the steam valves only will be explained.

To ascertain the length of the eccentric-rod, unhook it, and put the rocker-arm in its mid-position. Assuming the wipers to be placed in their correct positions in relation to the rocker-arm, the mid-position of the latter may be found by moving it until corresponding points on the wipers, at the same distance from the center of the rocker-shaft, are the same distance from the toes, the distance to be measured parallel to the lifter rods. Having found the mid-position, the rocker-shaft may be held in position by screwing down the caps of its bearings. Next place the crank on one of its dead centers, proceeding in the same manner as explained in Art. **1040.** Now lower the eccentric-rod until it will just rest on the rocker-arm pin. The next step is to turn the eccentric around on the crank-shaft until the center of the crank-shaft, the center of the eccentric, and the center of the rocker-arm pin are in the same straight line. The proper position of the eccentric may perhaps best be found by watching the end of the eccentric-rod. When it is just about to reverse its motion, the eccentric is in its required position. Hold the eccentric and make a fine center punch mark on the face of the rocker-arm pin, and another mark on the side of the eccentric-rod at any convenient distance, say about 12 inches, from the first mark and towards the crank-shaft. Set a tram to the two marks made, measure the distance, and add to it the distance from the center of the crank-shaft to the center of the eccentric (one-half the throw). Reset the tram to the new measurement and move the eccentric on the crank-shaft until the center punch marks coincide with the points of the tram.

Hold the eccentric in position, and lengthen or shorten the eccentric-rod until the hook will just drop over the rocker-arm pin. If two steam eccentrics are employed, before proceeding further, adjust the length of both eccentric-rods in the same manner as explained. The eccentric-rods will be approximately adjusted now. Next loosen the rocker-shaft and hook in the eccentric-rod. Now, turn the eccentric

until the valve that is being set has the lead determined upon; if two eccentrics are used, perform the same operation for both. Next fasten the eccentric or eccentrics to the crank-shaft, and place the crank on the opposite center. Then, if there is found to be a difference in the leads, lengthen or shorten the eccentric-rods until one-half this difference has been made up. The proper length of the eccentric-rods has now been found; the lead will be equal on both sides, but either more or less than that determined upon. To give the proper lead, move the eccentrics until it is seen that the valves possess the amount desired. After the valves are set for equal lead, to prove the correct adjustment of the wipers in relation to the rocker-arm, measure the distance each steam valve lifts, turning the engine over by hand. If their lifts are found to be equal, the wipers are correctly adjusted. If found unequal, however, one of the wipers will have to be raised or lowered. In connection with this it should be remembered that raising the wiper will give a greater lift to the valve, and *vice versa*. After the wiper is shifted, the rocker-shaft must be put into its mid-position and secured there. Now readjust the eccentric-rods again, proceeding in the same manner as before. Then adjust eccentrics and rods for equal lead, and try the lift again. Repeat all operations in their order until the valves operate properly. After these adjustments have been made, the cut-off may be tried. If not taking place when desired, unhook the eccentric-rods and place the rocker-shaft in mid-position as near as possible. Then either raise or lower both wipers an equal amount measuring from the toes to corresponding points on the wipers, the measurements to be made in a direction parallel to the lifter rods. Find by trial the position of the pin in the rocker-arm at which the valves will have the required lift. Then adjust the eccentric-rods, and shift the eccentrics until equal lead is obtained. Try the cut-off again, and repeat the operations in their order, if necessary.

No rules can be given as to the position of the eccentrics in relation to the crank, as that depends on the relative arrangements of the toes, wipers, and rocker-arm.

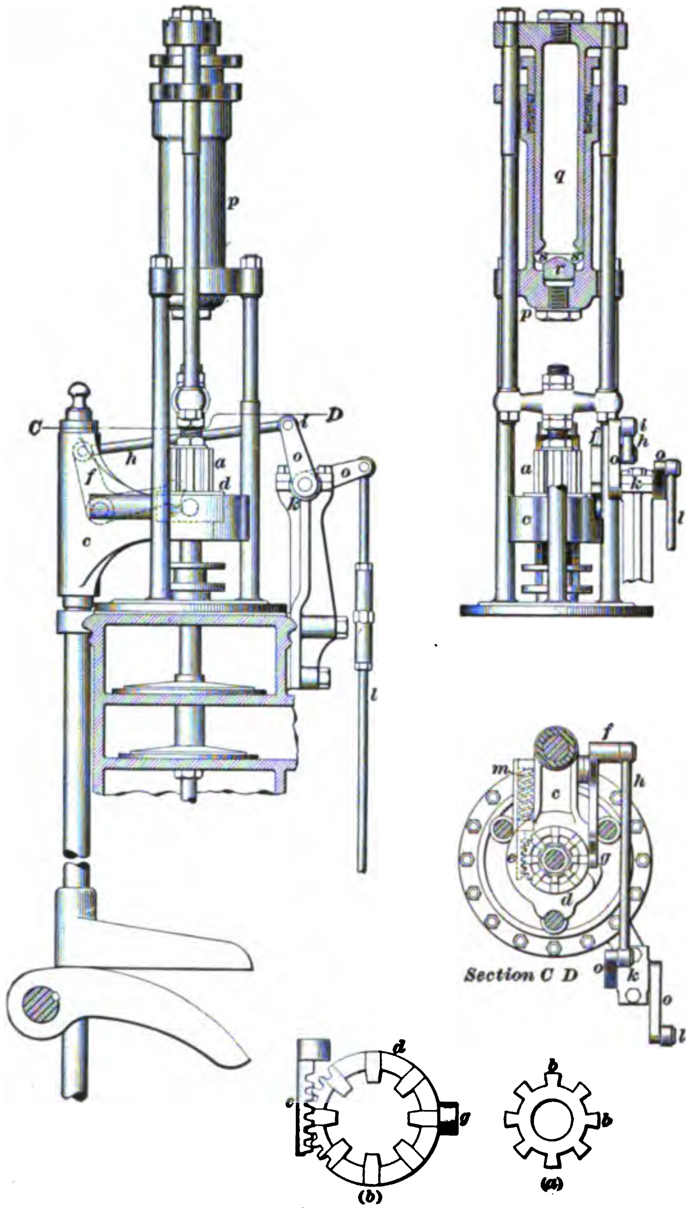


FIG. 333.

1123. Sickels' momentarily adjustable cut-off is made in a variety of forms, the principle of operation being the same in all of them. The steam and exhaust valves, which are usually of the double-seat poppet type, are lifted in the same manner as in the Stevens' gear. The exhaust valves, as usually arranged, are opened and closed in precisely the same manner as previously described. The lifting mechanism for the steam valves is so adjusted that there is no interval between the raising of one lifter rod and the lowering of the other. Cut-off is effected by detaching the valves automatically from the lifter rods; gravity returns the valves to their seats while the rods continue in motion. By an exceedingly simple mechanism, the valves can be detached from the lifter rods at almost any point of the stroke while the engine is in motion. The construction of the valve gear is as follows: The die *a*, shown enlarged at (*a*), Fig. 333, is rigidly attached to the valve stem. The die is provided with eight projections, or teeth *b*, which extend the whole length of the die, and are faced with steel at the lower end. The lifter-rod bracket *c* is recessed central with the valve stem, the die lifter *d* fitting into the recess.

An enlarged view of the die lifter is shown at (*b*), Fig. 333. The die lifter may be partially revolved within the bracket. A bell-crank *f* is fulcrumed to the lifter-rod bracket. Its horizontal member is cam-shaped at the free end. In a certain position of the lifter rod, it engages the roller *g* (see *Section C D*), carried on a stud screwed to the die lifter, thus partially revolving the die lifter. Pivoted to the vertical member is the radius rod *h*, which has its fulcrum at *i* on the movable drop bell-crank *o* turning on the fixed center *k*. The drop bell-crank, which is stationary while the engine is in motion, may be moved and held in any desired position by means of the reach rod *l*, which, for convenience, is attached to a lever and quadrant (not shown in the figure).

1124. The operation of the cut-off mechanism is as follows: When the lifter rod is in its lowest position, the die lifter is so placed, automatically, in relation to the die

that the teeth of the die and die lifter match. Hence, the lifter rod when moving upwards soon engages the die and raises the valve. But since the fulcrum of the bell-crank *f* moves with the lifter rod while the fulcrum *i* of the radius rod remains stationary, it follows that, with *i* in the position shown, the horizontal member of the bell-crank moves upwards until the radius rod and lifter rod make a right angle with each other. After the radius rod passes this position, the horizontal member moves downwards until its cam-shaped end engages the roller in the die lifter, and rotates it sufficiently to bring the teeth of the die in line with the spaces of the die lifter. The die now, being freed, drops through the die lifter, and the valve closes, thus cutting off the steam quickly and preventing any wire-drawing. The lifter rod, now detached from the valve, continues to rise until it reaches its highest position; it then returns, and as soon as it brings the die lifter below the die, a spring *m*, acting upon the rack *e*, returns the die lifter to its original position; the teeth of the die and die lifter now match again, and everything is in readiness for the next stroke. The time at which the die will be released from the die lifter depends entirely upon the relative position of the fulcrum *i*. When the latter is shifted towards the lifter rod, cut-off takes place later; when moved away from the lifter rod, cut-off occurs earlier. From this it follows that the time of cut-off may be varied at will by varying the position of the bell-crank *o*.

1125. As stated above, gravity returns the valve to its seat when released. But since the weight of the valve is considerable, it would strike the seat with a heavy blow if allowed to fall freely. To prevent this shock, and at the same time to allow the valve to seat quickly, a contrivance known as a **dashpot** is attached to the valve stem. In the figure, *p* is the dashpot, which is fitted with a hollow plunger *q*, working through a stuffing-box. The lower end of the hollow plunger carries a supplementary plunger *r* fitting into a cylindrical recess in the bottom of the dashpot.

The dashpot is filled with either water or oil. When the valve is detached, the liquid in the dashpot escapes through the openings *s*, *s* into the hollow plunger, the size of the openings governing the rapidity with which the valve seats. The valve continues to descend until the liquid within the recess arrests the motion of the plunger, which should take place just when the valve touches its seat. The quantity of liquid within the dashpot may be regulated by means of two cocks; through one, the dashpot may be filled, and through the other one, emptied. An insufficient quantity of the liquid is made evident by the slamming of the valve. If too much liquid is contained within the dashpot, the valve will "hang open," that is, it will not seat entirely.

THE ENGINE ROOM.

ENGINE-ROOM FITTINGS.

THE KINGSTON VALVE.

1126. The **Kingston,** or **main injection, valve** is a valve secured to the skin of the ship below the water-line. By means of this valve the supply of condensing water is admitted to the circulating pump or to the condenser. It is made in two forms. In the first form the valve is so arranged that it is opened against the pressure of the sea-water. It is claimed for this arrangement that the water will automatically close the valve in case of any accident to the valve stem or bonnet. Perhaps the more common practice is to construct it like an ordinary stop-valve, that is, make it close against the pressure of the water.

If the bonnet or valve casing should fracture from any cause, the latter construction being used, the sea-water will run directly into the vessel and perhaps cause it to sink. If any accident of the above nature should happen, the first step should be to pass a tarpaulin over the side of the vessel, and secure it over the opening for the Kingston valve. If properly done, this will, to a great degree, alleviate the inrush of water, and allow repairs to be made. The opening in

the ship's skin (the term *skin* is used in connection with iron vessels) is always covered by a strainer to prevent sea weed, etc., from entering the pumps or condenser.

THE BILGE INJECTION.

1127. Ail modern steam vessels are provided with piping attached to the main injection pipe and leading to the bilge. This is done to enable the circulating pump or the condenser to draw the supply of condensing water from the bilges in case the vessel springs a leak. A valve known as the **bilge-injection valve** is fitted to the bilge-injection pipe; when pumping from the bilges, this valve is opened, and the Kingston valve is closed. In the best modern practice, the bilge-injection valve is made of the non-return pattern; that is, it is a check-valve similar in construction to that of an adjustable lift-feed check-valve. It is so placed on the pipe that when pumping from the bilges the water can pass freely through the valve, but when drawing the condensing water from the sea, the sea-water will hold the valve down. This construction is adopted for the purpose of preventing a careless attendant from sinking the vessel. The end of the bilge-injection pipe should always be provided with a strainer, to prevent any waste, chips, etc., from entering the pumps. When using the bilge-injection, it is considered good practice to station a man at the strainer with orders to prevent its clogging.

BILGE PIPING AND MUD BOX.

1128. Since every vessel leaks more or less, and since all water collects in the bilges, means for pumping out the latter must be provided. To enable this to be done readily, a system of piping leads from some central point to the different bilges. To simplify the piping as much as possible, that is, to allow the various pumps to draw from the bilges through a one-pipe system, the various branches of the bilge-pipe system are usually connected to a **mud box,** or, as it is frequently called, a **directing box.** This is usually located in the engine room close to the pumps. It is a

rectangular closed cast iron-box, divided by a strainer into two compartments. The suction pipes of the various pumps are connected to stop-cocks or valves bolted to one end of the box and opening into one of the two compartments. The bilge suction pipes are attached to stop-cocks or valves communicating with the other compartment. This arrangement allows any pump attached to the mud box to pump from any bilge through the same pipe system. The mud box is provided with a removable cover to allow the strainer to be readily cleaned.

1129. Nowadays all the bilge piping is made of lead, experience having shown this material to be superior to any other in point of durability. Each bilge pipe should be provided with a strainer; the aggregate area of the holes in the latter should be at least one and one-half times the area of the pipe, and preferably more. Since the bilge piping is made of a yielding, non-elastic material, it is frequently dented or flattened out by accidental blows, etc. Since this may prevent the pumping out of the bilges when most urgent, the bilge piping must be frequently overhauled.

DELIVERY VALVES.

1130. Each outboard delivery pipe is usually connected to a so-called **delivery** valve attached to the ship's skin. It is constructed like a check-valve, and so placed in relation to the pump that the water discharged by the latter can pass freely through the valve, but no sea-water can flow back to the pump.

WATER SERVICE.

1131. To allow water to be applied to the slides, to the different bearings, to the eccentrics, and to the cross-heads in case of necessity, a system of piping is always fitted. The water supply is usually taken from the water end of the condenser; if the circulating pump is worked directly by the engine, the pipes are usually arranged so that water may be taken from the condenser, or that water may be delivered to the water service by the donkey pump. The water

circulating through the thrust bearing and spring bearings is usually taken from the inside of the stern tube. This keeps up a constant circulation in the latter.

THE PRESSURE-REDUCING VALVE.

1132. If the main boilers carry a high steam pressure, and if steam from them is to be used for running the winches, the steering engine, electric-light engine, etc., the pressure of the steam will generally have to be reduced. This may be done automatically by a valve specially constructed for this purpose.

1133. The **Foster pressure-reducing valve** is shown in section in Fig. 334. The steam inlet is at A; the outlet may be at either B or C. Two valves, e and g, connected together by the sleeve H, are rigidly attached to the valve stem G, being secured thereon by a nut and split cotter. The valves are guided by four wings, as shown; the valve stem is guided in a hole in the bonnet U. When the valve is not in use, the valves e and g are wide open. The operation of the valve is as follows:

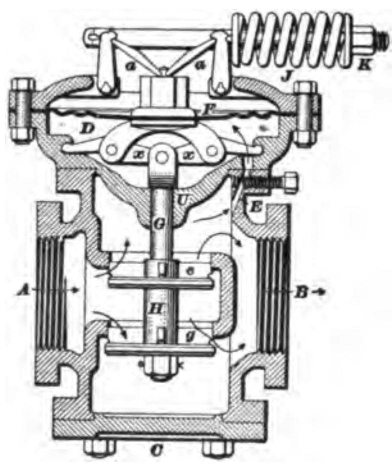


FIG. 334.

When steam is first admitted it passes through the annular openings between the valves and their seats to the outlet. Some of the steam on the outlet side of the valve passes through the small steam port E, the opening of which is regulated by a set-screw into the diaphragm chamber D; it acts on the under side of the diaphragm F and forces it upwards until the force exerted on the diaphragm by the steam balances the resistance of the spring J. As is well

known, the resistance of a spring increases very rapidly when compressed. To counteract this increased resistance, the diaphragm acts upon the spring through the intervention of the toggle joint *a a*, which allows the diaphragm to act with an increasing leverage when forced upwards. The toggle joint is so proportioned that the movement of the diaphragm is directly proportional to the steam pressure. In order that a small movement of the diaphragm may cause a large movement of the valves, the valve stem is not connected to the diaphragm, but to a pair of multiplying levers *x*, *x*. When the pressure of the entering steam is increased, the increased pressure will force the diaphragm upwards, the valves move towards their seats, and the area of opening is decreased. This wire-draws the steam to the pressure for which the valve is set. When the pressure of the entering steam is reduced, the reverse of the above takes place. Since the area of opening (and, hence, the steam pressure on the outlet side) depends upon the relative position of the valves in regard to their seats, and since the position of the valves is governed by the resistance of the spring *J*, it follows that the pressure to which the valve will reduce the entering steam may be adjusted by increasing or diminishing the resistance of the spring *J*. To allow this to be readily done, a nut *K* is provided. The device illustrated will not only reduce the pressure, but will also regulate it automatically; that is, although the pressure of the entering steam may vary considerably, as long as its pressure does not fall below the pressure for which the valve is set, it will give a practically uniform pressure on the discharge side. A steam gauge must be fitted to the steam pipe on the discharge side.

BY-PASS VALVES.

1134. Compound, triple, and quadruple expansion engines are always fitted with by-pass pipes and valves. By means of these pipes and valves, live steam from the main steam pipe may be admitted to the intermediate and low-pressure receivers for the purpose of facilitating the

handling of the engines as well as to allow them to be readily warmed up when starting. When the high-pressure crank is on either dead center, it will be plain that the engine can not be started unless the crank is moved beyond the dead center. If no by-pass valves are fitted, this must be done by hand, i. e., by means of the jacking wheel and gear. With a by-pass valve fitted, live steam may be admitted to the low-pressure or intermediate cylinder, thus pulling the high-pressure crank off the center. In some instances the by-pass valve does not admit steam to the receiver, but to the cylinder directly. In that case the valve is a modified slide valve, by means of which steam may be admitted at will to the top or bottom of the cylinder. The valve is simply a flat plate without any exhaust cavity, sliding on a flat valve seat provided with two ports leading to the respective ends of the cylinder. The valve is made long enough to cover both ports in its mid-position. The valve may be moved by means of a hand lever attached to the valve stem.

THE JACKING GEAR.

1135. To allow the engines to be turned over by hand, a worm-wheel is frequently keyed to the shaft. A worm, driven either by a steam engine or by a large ratchet, may be made to engage the worm-wheel, and may be readily disengaged therefrom. Giving motion to the worm results in turning the crank-shaft, the direction in which the latter turns depending upon the direction in which the worm turns. Small engines are usually provided with a jacking wheel having recesses cast into the crown of the wheel. A pinch bar or crow bar may be used for turning the engine in that case.

CYLINDER RELIEF VALVES.

1136. Relief valves, which are simply spring-loaded safety valves set to open at a pressure of say 20 pounds more than the initial pressure in the cylinder, are usually attached to both ends of the cylinder, and often to the receivers. Their purpose is to relieve the cylinder and prevent

a break-down in case water should collect in the cylinder, or in case the pressure should become too high from any cause. Relief valves are shown at *I* and *L*, Fig. 261, Art. **955.**

DRAIN COCKS.

1137. Drain cocks are always fitted to the cylinders, and should be fitted to any part of the engine in which water is liable to collect. In warming up the engine, or whenever a clicking noise indicates the presence of water in the cylinder, they should be opened to allow the water to escape. In condensing engines it is the common practice to lead the drain pipes to the condenser, thus saving all the fresh water which would otherwise be blown off into the bilges.

LUBRICATORS.

1138. An automatic lubricator is a device by means of which a definite quantity of oil is delivered automatically and constantly into the steam chest or steam pipe, for the purpose of lubricating the internal rubbing surfaces of a steam engine or kindred apparatus.

FIG. 335.

1139. The simplest form of automatic lubricator is shown in Fig. 335, which consists of a cylindrical shell, or receptacle *A*, provided with a central tube *a*, a cap *C*, a threaded shank *b*, for attaching the lubricator to the steam chest or steam pipe, and a valve *B* for establishing communication between the lubricator and steam chest.

The operation of the lubricator is as follows: The receptacle is filled with oil and closed. The valve *B* is then opened, thus allowing the steam to pass through

the central tube in to the top ofthe lubricator. The steam, coming in contact with the cold surfaces of the oil and receptacle, condenses. Since water is heavier than oil, bulk for bulk, the drops of condensed steam sink to the bottom of the receptacle. As two bodies can not occupy the same space at the same time, the drops of water displace a quantity of oil equal in volume to their own; the oil, which has no other means of egress, flows over the edges of the central tube and runs by gravity into the steam pipe.

1140. The simplest kind of **sight-feed** lubricator is shown in Fig. 336. Its principle of action is practically the same as that of the lubricator shown in Fig. 335; i. e., it depends upon the condensation of the steam, and the subsequent displacement of the oil. Its construction is as follows: A cylindrical receptacle *d* is provided with a central tube *a* communicating with the threaded shank *e* and the sight-feed glass *A*. To fill the receptacle, the cap *E* is provided. The upper end of the lubricator communicates with the sight-feed glass by the passage *b*. In operation the steam is admitted to the lubricator by means of the valve *B*, the opening of which admits it to the inside of the lubricator as well as to the sight-feed glass *A*. The steam, coming in contact with the oil and the top of the lubricator, condenses and

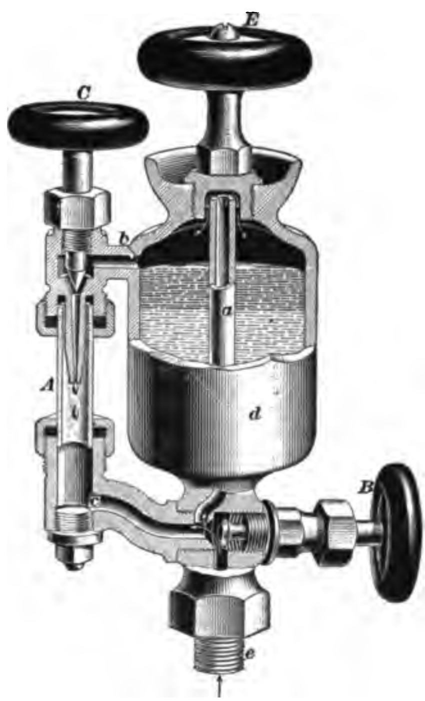


FIG. 336.

displaces the oil, which then flows through the passage *b* into a conical nozzle, as shown, and issues from the latter either drop by drop or in a thin stream, depending upon the position of the regulating valve *C*. It is apparent that, by screwing the latter down, the annular opening between the valve and nozzle is reduced, and, hence, the flow of oil is checked. Conversely, by screwing the valve up, the rate of flow is increased. The drops of oil issuing from the nozzle flow by gravity through the passage *c*, and thus to their destination. Since the glass tube is transparent, the oil dropping from the nozzle is in plain sight of the attendant. By means of a drain cock, not shown in the figure, the lubricator may be emptied when required. This lubricator is invariably of the **down-feed** type, which means that the oil is discharged downwards in respect to the feed nozzle. These lubricators are not very reliable in their action, since the oil is not forced through the feed nozzle, but flows through it by gravity. This style of lubricator must be placed on top of the steam chest or on top of the steam pipe (in the case of a horizontal pipe).

1141. The lubricators shown in Figs. 335 and 336 belong to the single-connection type, this meaning that the oil must pass through the same passage by which the steam is admitted.

In Fig. 337 a lubricator of the double-connection up-feed type is shown. In this style of lubricator the steam does not come into contact with the oil at all. Instead of the oil flowing through the feed nozzle by gravity alone, it is forced through it by hydrostatic pressure. The construction of the lubricator differs somewhat from those previously described. No central tube is provided, since no steam enters the lubricator. The receptacle *o*, which may be filled by unscrewing the cap *m*, communicates with the sight-feed glass *c*. The regulating valve *i* controls the flow of the oil. At *j* a valve used for draining the receptacle is shown; the drain pipe may be attached by the union *k*. The valve *l* may be used for closing the passage leading from the bottom

of the lubricator to the pipe *a*. The lubricator is connected to the steam pipe *n* by the pipe *a*, which connects *o* to the condenser *p*, which is in turn connected to *n* by the pipe *f*. The oil from the lubricator passes to the steam pipe through the pipe *b*. By means of the valves *g* and *h*, the lubricator may be shut off when desired. Its operation is as follows: When starting the cup for the first time, the pipes *a* and *b* and the sight-feed glass *c* are filled with water, the pipe *a* being filled nearly up to *d*. Since the water in the pipe *a* can flow into the bottom of the lubricator, it follows that the oil will be forced through the feed nozzle with a pressure depending upon the hydrostatic head *d e*.

FIG. 337.

After passing through the feed nozzle, the drops of oil ascend through the sight-feed glass and up the pipe *b*, the pressure causing the upward flow being due to the difference in specific gravities of the water and oil. To prevent the emptying of the pipe *b*, when draining the lubricator preparatory to replenishing the oil supply, a small check-valve *r* is provided. In order to replenish the water which passes from the pipe *a* into the lubricator, a so-called condenser is employed. This may be a vessel of any desired shape; in marine work it is usually a piece of 1½″ brass tubing, as shown in the figure. The steam entering the condenser from the steam pipe is condensed by coming in contact with the relatively cool surfaces of the condenser; the latter is

made large in order to increase the radiating surface. In this style of lubricator the pressure operating the device may be made as great as circumstances will permit by simply extending the loop of the pipe *f* higher up. If this be done the condenser must also be raised in order to derive the most benefit from the change.

Double-connection lubricators are especially adapted to, and hence almost universally used in, marine work, since they are most reliable in their action.

The better grades of lubricators are usually provided with a gauge glass which shows the amount of oil remaining in the lubricator.

MANAGEMENT OF ENGINES.

1142. To Start an Engine.—We shall assume the engine to be a three-cylinder triple-expansion surface-condensing engine. If an independent circulating pump is fitted, the Kingston valve should be opened first, the discharge valve on the outboard delivery pipe blocked open or tested to see if it is free to lift, and the circulating pump started for the purpose of keeping the condenser cool. We may now proceed to warm up the engine. Open all cylinder and receiver drain cocks, and then open the throttle a little to admit steam to the high-pressure valve chest. Open the by-pass valves and admit steam to the receivers. After the steam chest and receivers are warmed up, both ends of the cylinders should be warmed up. To do this, move the valve gear from the go-ahead to the go-astern position, and *vice versa*, for some length of time. Now open the throttle wide enough to just set the engine in motion. Before the high-pressure crank reaches the center, reverse the engine, and keep the crank playing back and forth for some time before allowing the engine to make a revolution. When sure that everything has been thoroughly warmed up, the engine may be started up very slowly, its speed being gradually increased. The drain cocks may now be closed.

Before starting the engine it is necessary to oil all the bearings; it is also considered good practice to turn the

engine through one revolution by hand to make sure that nothing is foul of the working parts. If the feed-pumps are worked from the engine, open the feed check-valves on the boilers before starting.

A beam engine may be warmed up by tripping the valves with the starting bar. Just before moving the engine, open the blow-through valve on the condenser to blow out all the air. Then open the injection valve to admit the condensing water, and work the engine back and forth. When a beam engine or any engine fitted with a jet condenser is stopped, always shut off the injection valve to prevent flooding of the condenser. When the engine is standing, a jet condenser will sometimes get so hot that the injection water, which flows in by gravity, can not enter, owing to the pressure of steam within the condenser. This is caused by leaky steam and exhaust valves. In such cases cool the condenser by external application of cold water; or, if conditions allow it, force water into the condenser by using the donkey pump, for the purpose of condensing the steam within it.

1143. A marine engine may fail to start from a great many different causes, some of which are here enumerated:

1. The high-pressure valve, if a slide valve, may be away from its seat, thus admitting steam to both sides of the piston.

2. The jacking gear may not be disengaged from the crank-shaft.

3. The propeller or paddle-wheels may be fouled by a rope or piece of timber.

4. An obstruction may be in the crank pit or in the cylinder.

5. The valve stem may have been broken, or the nuts securing the valve to the stem may have slackened back.

6. The cylinders may be filled with water.

7. Some of the bearings may be screwed up too tight, or the piston or piston-rod packing may be too tight.

8. If a brake is fitted to the propeller shaft, it may grip the shaft.

9. The air pump may be choked with water, owing to the discharge valve on the hotwell delivery pipe being secured down by an ignorant person.

10. The throttle-valve spindle may be broken.

11. One of the eccentrics may have shifted on the shaft or may be broken.

12. If the engine has been overhauled, the eccentric-rods may have been connected to the wrong ends of the link.

13. If a separate expansion valve is used, it may be set to cut off too early.

14. Receiver may be broken so as to admit steam to both sides of the piston.

15. The condenser may be flooded.

16. The crank-shaft, line shaft, or thrust shaft may be broken and jammed.

1144. There are many other possible defects besides those enumerated which may prevent the starting of the engine. Any of them, however, can be found by a systematic examination. Proceed thus: If the engine fails to start, and it is known not to be due to the steam supply being cut off, try to turn the engine over by hand or by means of the jacking gear. If this can be done readily, the trouble must be looked for in the valve gear, or if on examination this is found to be in order, examine the steam chests and receivers to see if anything has broken in such a manner as to admit steam to both sides of the piston. If the engine can not be turned by hand, look for the obstruction and remove it.

1145. Air Pump Broken Down and No Separate Exhaust Possible.—Ordinarily this will disable the engine, and the vessel will have to proceed under sail. If the auxiliary pumps can pump from the steam end of the condenser, the air pump may be disconnected from the engine, the circulating pump started, and the engine may then be

run at a reduced speed, the auxiliary pumps removing the condensed exhaust steam from the condenser. No vacuum will be formed, however, unless the auxiliary pumps are large enough to act as air pumps.

1146. Go-Ahead Eccentric Broken Irreparably.—If this happens on a multiple-crank engine, there is the choice of several methods of procedure. One way would be to disconnect the disabled engine entirely and conduct the steam to the other engine or engines by the shortest route. For instance, assuming the high-pressure engine of a fore-and-aft compound to be disabled in this manner, disconnect the connecting-rod from the shaft and cross-head. Let the piston rest on the bottom of the cylinder, and secure it by shores from the cross-head to the cylinder bottom. Remove the high-pressure valve, and block up both steam ports by filling them with blocks of soft pine wood driven in tightly. The steam from the steam pipe may now pass into the high-pressure steam chest through the high-pressure exhaust port into the low-pressure receiver, and thence to the low-pressure engine. Remove the disabled valve gear, and the engine is ready to start. In the above it has been assumed that the pumps are worked from the low-pressure cross-head. In some instances, however, the pumps are worked by the high-pressure engine. If that is the case proceed thus: Remove the piston from the piston rod of the disabled engine, or remove the piston and its rod if that can be more readily done. Leave the cross-head and connecting-rod in position, but remove the valve and valve gear, and block up the steam ports. By running with the low-pressure engine, the high-pressure crank will work the pumps. The above methods allow the engine to be worked in either motion; they may be employed to remedy other break-downs besides the one mentioned at the beginning.

Another way of getting the engine to run again would be to shift the go-astern eccentric to take the place of the broken one. The go-astern end of the link must then be

slung by a rope, chain, or tackle to prevent it from dropping. The engine can not be reversed if this method is employed.

1147. Cylinder Head Broken.—Repair it if possible. If not possible, the steam port next to the broken head may be blocked up, thus running the disabled engine single-acting.

1148. Piston or Piston Rod Broken.—It it can not be repaired, disconnect the disabled engine, and run with the other or others.

1149. After Crank-Pin Broken.—If the crank-shaft is made in interchangeable sections, disconnect the high-pressure engine and shift the high-pressure crank-shaft into the place occupied by the broken shaft. If pumps are worked from high-pressure cross-head, repair the broken after crank in the best manner conditions will allow, making the repairs strong enough to stand the strain of working the pumps. Put the low-pressure crank-shaft in place of the high-pressure crank-shaft, connect the connecting-rod and cross-head to it, and remove the high-pressure piston. Block up the steam ports and start the engine slowly, running it as fast as your judgment deems it to be safe.

No hard and fast rules as to how to act in case of a break-down or how to manage and repair the engine can be laid down, since the construction of the engine, the facilities for executing repairs, etc., have to be taken into account. What has been said in this section is intended merely to be a hint how to act in certain emergencies. In applying the hint given, the student must remember that "circumstances alter cases," and use his judgment to the best advantage.

1150. To Line Up the Cross-Head.—In course of time the shoes of the cross-head will wear away until the axis of the cylinder and the line of motion of the piston rod are no longer in the same straight line. To bring the cross-head back to its proper position, proceed thus: Turn the engine in the go-ahead motion until it reaches the top center. With a pair of inside calipers measure from the

go-ahead guide to the piston rod, taking care to measure perpendicularly to the surface of the guide. Turn the engine ahead until it reaches the bottom center, and from the same spot on the surface of the guide from which the first measurement was taken, again measure the distance to the piston rod perpendicularly to the surface of the guide. If the two measurements correspond, the cross-head is in line. Usually, however, the second measurement will be found to be larger than the first. Put a thin liner behind the shoe on the go-ahead side, secure the shoe to the cross-head, and repeat the operations until the two measurements correspond. In the above it has been assumed that the guides are in line with the cylinder.

1151. To Find on which Guide the Pressure Acts.—This may be determined by the following rule: Stand by the thrust block and look towards the engine. If the piston on its down stroke turns the crank to the right, the guide to your left will be the one on which the cross-head rubs. Conversely, if the crank turns to the left, the guide at your right receives the pressure.

CALCULATIONS RELATING TO FEED-PUMPS FOR MARINE SERVICE.

1152. The amount of water to be pumped into the boilers is not only the quantity evaporated into steam and used by the engine, but also the quantity blown off for the purpose of keeping the saturation constant. To this must be added the quantity of water of the boilers, pipes, etc., lost by leakage. A little consideration will show that the feed-pump for an engine fitted with a jet condenser must be considerably larger than if a surface condenser were fitted to the same engine, since with a jet condenser sea-water is fed to the boilers; hence, blowing-off has frequently to be resorted to in order to keep the saturation down.

1153. If a surface condenser is fitted, the size of the feed-pump may be found in the following manner: Suppose

that we have a compound engine 18″ and 30″ × 20″, to cut off at 10 inches from the commencement of the stroke. Boiler pressure is 90 pounds, absolute. Then, the volume of steam used per stroke will be, approximately, the clearance volume plus the volume swept through by the piston up to the time cut-off takes place. The volume of steam used per stroke should only be calculated for the high-pressure cylinder, since the low-pressure cylinder is not supplied with steam from the boilers, but receives its steam supply from the high-pressure cylinder. If the clearance volume is not known, assume it to be 10 per cent. of the volume swept through by the high-pressure piston. Even if this is not the right volume, it is close enough for the purpose. Then, assuming the clearance to be 10 per cent., the clearance volume of the high-pressure cylinder is $.10 \times 18^2 \times .7854 \times 20 = 508.94$ cu. in. The volume swept through by the high-pressure piston up to the time cut-off takes place, is $18^2 \times .7854 \times 10 = 2{,}544.7$ cu. in., nearly. Hence, the total volume of steam used per stroke is $508.94 + 2{,}544.7 = 3{,}053.64$ cu. in. Since single-acting plunger feed-pumps worked directly from the engine make one delivery stroke for every two strokes of the engine, the volume of steam used by the engine for every delivery stroke of the pump is $3{,}053.64 \times 2 = 6{,}107.28$ cu. in. From the steam tables, the ratio between the volume of steam at 90 pounds, absolute, and water at its maximum density is 299.4. Hence, $6{,}107.28 \div 299.4 = 20.4$ cu. in. of water, nearly, are to be delivered at each delivery stroke of the pump. This quantity of water just calculated we shall call the **net feed-water.** If the pump were to deliver exactly the theoretical quantity of water per stroke, and if absolutely no water were lost from any cause, the net feed-water would be the quantity of water to be delivered. Since this is a theoretical assumption never realized in practice, and since we must provide for any emergencies, each feed-pump, if two or more are used, is made large enough to deliver at least three times the amount of net feed-water, assuming the efficiency of the pump to be 100 per cent.; that is, to fill entirely at each

stroke. We shall assume two pumps to be used, the stroke of the plunger being 10 inches. Then, the water to be delivered by each pump for every revolution of the engine (in case of emergency) is $20.4 \times 3 = 61.2$ cu. in. Since the stroke of the plunger is 10 inches, its area, in order to displace 61.2 cubic inches, must be $61.2 \div 10 = 6.12$ sq. in. The diameter corresponding to this area is $2\frac{13}{16}$ inches, nearly.

1154. If only one feed-pump worked directly by the engine is fitted, it is customary to make it capable of delivering six times the net feed-water used, for every two strokes of the engine. Assuming the stroke to be 10 inches, as above, the volume of water to be displaced by the plunger will be, in this case, $20.4 \times 6 = 122.4$ cu. in.; hence, the area of the plunger will be $122.4 \div 10 = 12.24$ sq. in. The diameter corresponding to this area is 4 inches, nearly, which will be the diameter of the plunger for this case.

1155. If a jet condenser is fitted, the conditions are different. The net feed-water per stroke may be calculated in the same manner as above. But since the pump must also supply the water blown off from the boiler for the purpose of keeping the saturation constant, the pump must not only supply the net feed-water, but also an additional quantity varying with the saturation.

Rule 187.—*To find the actual quantity of water the pump must supply per stroke (i. e., the* **gross feed-water***), multiply the numerator of the fraction expressing the saturation at which the boiler is to be worked, by the number of cubic inches of net feed-water per stroke, and divide the product by the above numerator, less 1.*

Let a = the numerator of the fraction expressing the saturation the boiler is to be worked at;

b = the net feed-water per stroke in cubic inches;

c = the gross feed-water (i. e., the quantity of water per stroke of the feed-pump).

Then,
$$c = \frac{a\,b}{a-1}.$$

Assuming the engine of the previous example to be worked jet condensing, and the saturation in the boiler to be kept at $\frac{2}{32}$, the gross feed-water for each delivery stroke of the plunger will be $\frac{2 \times 20.4}{2 - 1} = 40.8$ cu. in.

To provide for emergencies, it is customary to make each feed-pump, if two or more are used, large enough to deliver twice the gross feed-water, and if one pump only is used, four times the gross feed-water. The calculation may be made under the assumption that the pump fills at each stroke.

Assuming two pumps to be used, the stroke being 10 inches, the volume of water to be delivered by each will be $40.8 \times 2 = 81.6$ cu. in. Now, the area of the plunger will be $81.6 \div 10 = 8.16$ sq. in.; the diameter of a plunger having an area of 8.16 square inches is $3\frac{1}{4}$ inches, nearly.

Using only one pump, it should deliver $40.8 \times 4 = 163.2$ cu. in. of water. The area of the plunger will be $163.2 \div 10 = 16.32$ sq. in. and the corresponding diameter $4\frac{5}{8}$ inches, nearly.

The above calculations refer only to single-acting feed-pumps worked directly by the engine.

1156. When independent steam pumps are used, their size may be found as follows:

Calculate in the manner shown the volume of steam used per stroke of the engine, and multiply it by twice the number of revolutions per minute to obtain the volume of steam used per minute. From column 8 of the steam table, find the ratio corresponding to the pressure of steam carried; divide the volume of steam by this ratio to obtain the volume of water the steam would make when condensed. This will be the net feed-water per minute. Then, with a surface condenser, if only one independent pump is used, it should be capable of delivering at least six times the net feed-water per minute. If two or more independent feed-pumps are used, each should be capable of delivering three times the net feed-water per minute.

When a jet condenser is fitted, compute the gross feed-water in the manner shown, computing it per minute. If only one independent feed-pump is used, it should be capable of delivering four times the quantity of gross feed-water calculated. If two or more independent feed-pumps are used, each should be capable of delivering twice the gross feed-water calculated.

1157. Since steam pumps are bought of the builders, the engineer needs only to specify the volume of water they are to deliver per minute. An engineer must not expect to find in the market a size of pump rated by the builder which will deliver exactly the quantity of water calculated. He should remember that he may take a larger pump and run it slower, or take a smaller pump and run it faster, and deliver the same volume of water.

THE MACHINERY OF WESTERN RIVER STEAMBOATS.

THE ENGINES.

1. Introduction.—The conditions of service of the Western river steamboat differing considerably from those existing in the case of ocean steamers, lake steamers, and coasting steamers, a peculiar class of engines adapted to the service has been gradually evolved, and is employed to-day to the exclusion of all other types. While the machinery used may seem crude and uneconomical to persons accustomed to the machinery of large ocean and lake steamers, it is really a product of high engineering skill, inasmuch as it admirably answers the purpose it is designed for.

Owing to the low stage of the rivers at certain times of the year, the steamboats are shallow-draft vessels; the absolute necessity of shallow draft naturally calls for an engine that will develop the greatest amount of power for the smallest weight. While the use of a condenser increases the power and economy of an engine, the weight added practically prohibits its employment, except on steamers navigating only the lower part of the Mississippi, where there is sufficient water at all times of the year to allow of vessels of moderate draft.

Shallow-draft vessels having a hull which may be likened to a raft are necessarily very limber; as a matter of fact, it is essential that they be limber to allow them to be helped over sand bars and shallow places without serious straining of the hull.

Hence, there must also be considerable elasticity in the engines, to allow them to conform to the changes of shape of the hull. The changes in the shape perceptibly vary the distance from the engine to the wheel shaft, thus precluding the employment of a valve gear requiring fine adjustment in order to satisfactorily perform its function.

Furthermore, the frequent landings made and the crooked and narrow rivers require that the engines may be readily handled and that the wheel or wheels may be started from almost any position.

These conditions of service have been met by long-stroke, small-bore, high-pressure, non-condensing, horizontal engines, of slow rotative speed, having a valve gear operated by cams to give a quick opening and closing of the valves, and so arranged that it can be instantly changed from cutting off at part of the stroke to making the steam follow full stroke. Different types of engines from those hereafter described have been tried in numerous instances, but have usually proved costly experiments and been abandoned. The Western river engine, as it is built to-day, is a case of the survival of the fittest; and having stood the test of time—it being built to-day practically as it was 40 years ago—it is not likely that it will soon be superseded.

2. The engines employed in Western river service may be divided into two general classes, viz., **fixed cut-off** engines and **variable cut-off** engines.

3. The valve gear is almost invariably of the *lever* type, so called because the valve stem is attached to a lever similar to that of a lever safety valve. In small steamboats link-motion engines are used to some extent, the link operating a slide valve or piston valve. As these engines do not essentially differ from the vertical inverted slide-valve and link-motion engines in common use on board steamships, the principles of operation and adjustment being the same, they will not be considered here.

FIXED CUT-OFF ENGINES.

4. A fixed cut-off engine is shown in plan and elevation in Fig. 1. The illustration shows the general arrangement of the different component parts of the starboard engine of a stern-wheel steamboat. The port engine is an exact duplicate of the one shown; its crank is keyed to the wheel shaft at right angles to the crank of the starboard engine.

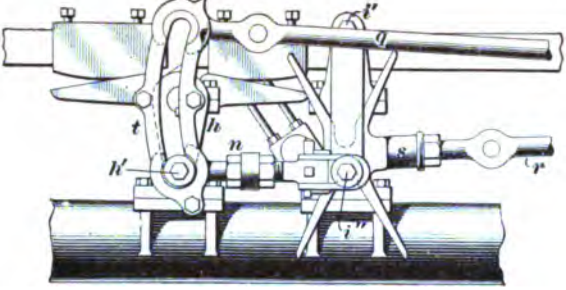
Two stout timbers *A* and *B* are bolted to the hull; they form the foundation for the engi... ...ese timbers carry the cylinder *C* and the guides *D*, *D*. The cylinder is bolted to two cast-iron sole plates on top of *A* and *B*; one of these sole plates is shown at *E*. The slides or guides are simply flat strips of metal bolted to blocks of wood secured to the timbers. A more elaborate construction of the guides will be shown later on in connection with the Rees variable cut-off engine. Steam is admitted to and exhausted from the cylinder by four independent poppet valves, the steam valves being inboards and contained in the valve chambers *F* and *F'*. The exhaust valves are contained in the valve chambers *G* and *G'*, placed outboards. The steam passes from the steam pipe *H* through the **steam side pipe** *H'* to the admission valves. The exhaust steam passes through the **exhaust side pipe** *K'* into the exhaust pipe *K*. The connecting-rod *L*, or **pitman,** as it is usually called by river engineers, is commonly made of wood and is strapped with iron, but of late hollow steel pitmans are coming into use. The valve gear is operated by cams, there being two of them in a fixed cut-off engine. The cam *M* is the **cut-off cam,** and operates the steam valves when the engine is cutting off. The cam *N* is the **full-stroke cam;** it operates both the steam and exhaust valves when steam is following full stroke, and the exhaust valves when the cut-off cam operates the steam valves. The cams are enclosed in the cam frames *M'* and *N'*, which are free to slide in the bearings *O* and *O'* back and forth in the direction of the axis of the cylinder. The motion of the cam frames is transmitted to the valve gear through the **cam rods** *Q* and *R* and **reach rods** *q* and *r*. The reach rods are hinged to the cam rods to admit

of their being shifted at will to connect with different points of the valve gear, for the purpose of bringing the latter under the influence of either the cut-off cam or the full-stroke cam, and of reversing the engine. The reach rods are operated by hand levers placed in a position where they are handy to the engineer when standing at the throttle ; these levers are connected with the reach rods by shafts extending from one engine to the other; the shafts carry the arms S and T and rods S' and T', as shown in the figure. To allow the hand levers to be shifted quickly and with ease, the weight of the reach rods, arms S, T, rods S', T', and some parts of the valve gear is counterbalanced by weights attached to crank arms keyed to the shafts mentioned.

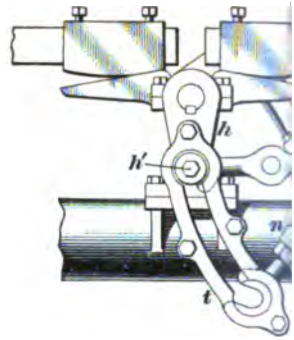
There are two engines for a stern-wheel steamboat, with the cranks set at right angles to each other. By connecting the reversing and cut-off gear to shafts and levers common to both engines, the change from one motion to the other, or the hooking on and detaching of the cut-off gear, is made simultaneously in both engines. The main steam pipe from the boilers is provided with a throttle; from the throttle the steam is led by branch steam pipes to each engine.

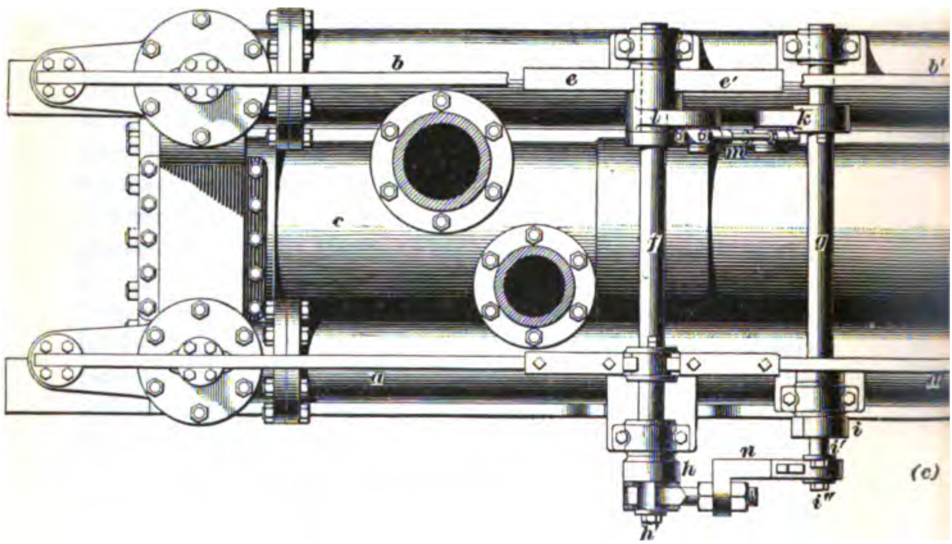
In Western side-wheel steamboats, the type of engine does not differ essentially from the engine just described; but as each wheel is entirely independent of the other, each engine has its own throttle, reversing mechanism, and cut-off mechanism. With the two wheels thus independent of each other, one wheel can be sent ahead and the other backed, thus allowing the boat to be turned very rapidly, a necessary feature in narrow and crooked rivers. In stern-wheel boats rapid maneuvering is made possible by three, and occasionally even four, balanced rudders.

5. The cylinder and valve gear of the engine illustrated in Fig. 1 are shown to an enlarged scale in Fig. 2. The view (*a*) is a side elevation of the cylinder and valve gear; the view (*b*) is a section on the line $A B$, looking forwards. View (*c*) is a plan, and views (*d*), (*e*), and (*f*) show, respectively, the positions occupied by the reach rods and their attached



(d)





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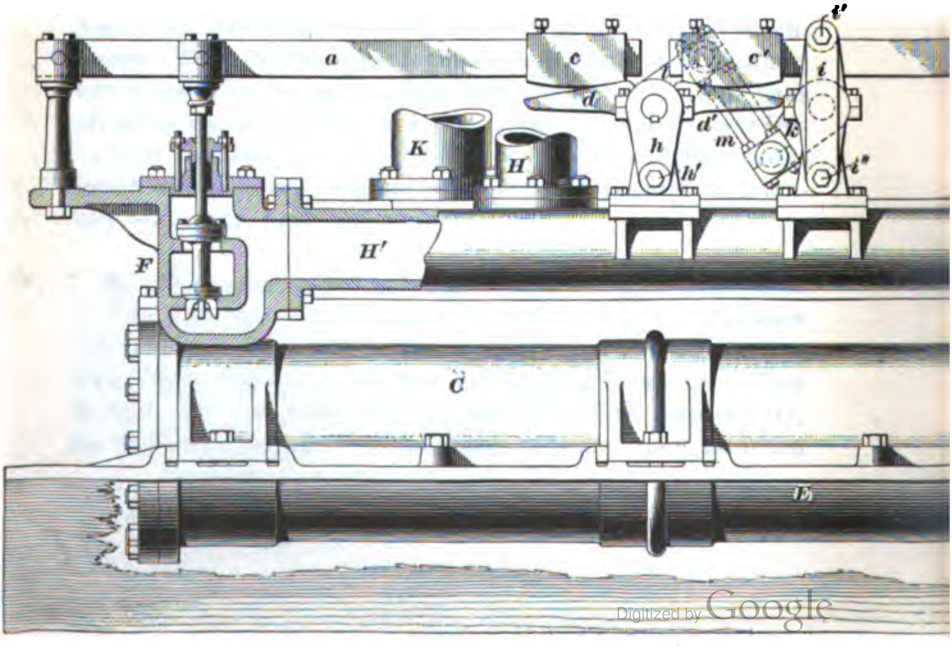
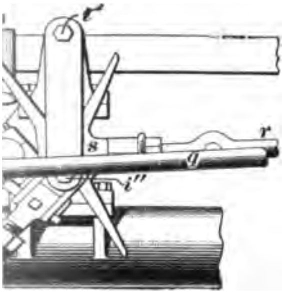


(a)

Fi



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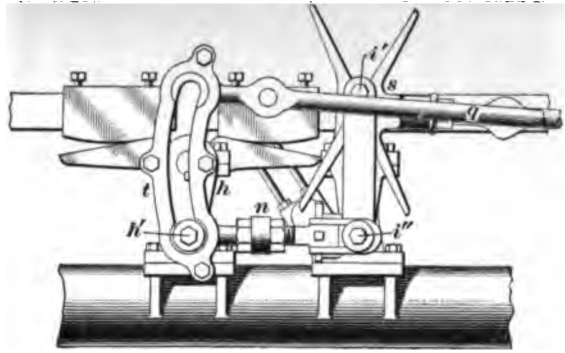
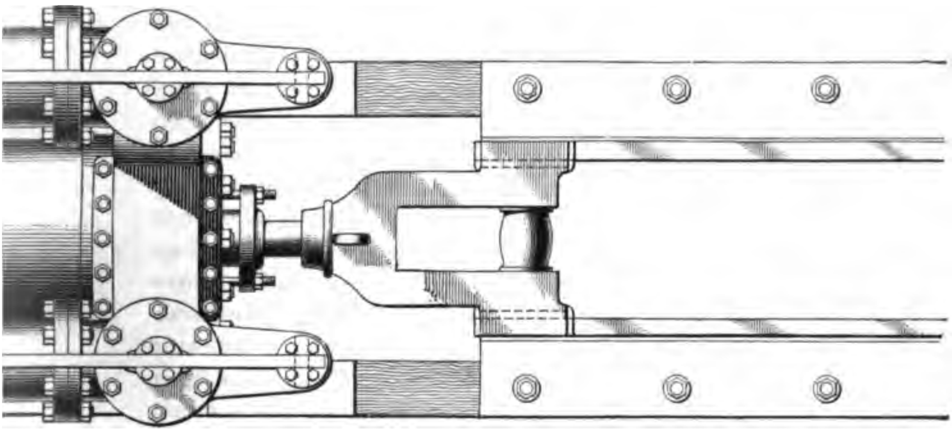
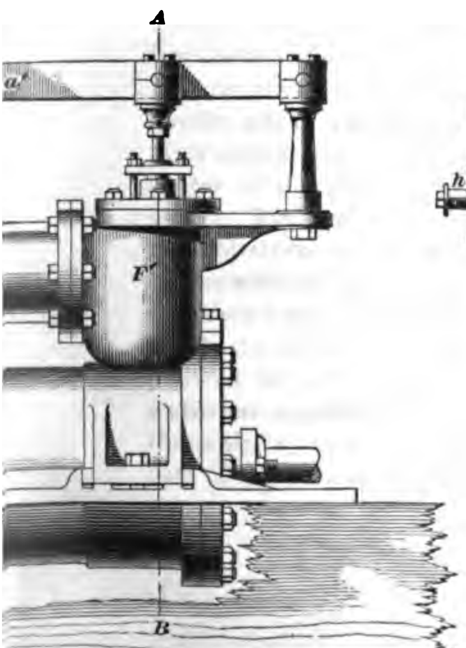
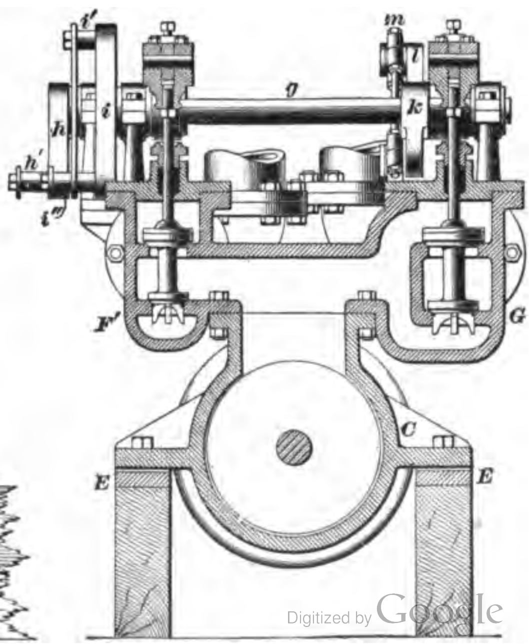


(f)







(b)

parts when running full stroke ahead, cutting off, and when in the backing motion. The valves are of the poppet type, either single-seated unbalanced, single-seated balanced, or double-seated valves; the valves of the engine here illustrated are double seated, as shown in view (*b*). They are connected to the levers by pin joints; *a* and *a'* are the **steam levers** and *b* and *b'* the **exhaust levers.** The four levers, one for each valve, are fulcrumed to standards securely bolted to lugs projecting from the valve chambers. Each lever carries a so-called **rider,** the steam lever riders being shown at *c* and *c'* in view (*a*). These riders serve a double purpose. In the first place, by their weight, they insure prompt closing of the valves; in the second place, they present a large contact surface to the **steam wipers** *d*, *d'* and **exhaust wipers** *e*, *e'*, thus decreasing the wear on the same. The steam wipers are keyed to the **forward rocker-shaft** *f*, while the exhaust wipers are free to turn about this shaft. The latter are confined longitudinally by abutting against the rocker-shaft bearing on the outboard side and a collar on the inboard side.

The **forward rocker-arm** *h* carrying at its lower extremity the pin *h'* is keyed to the forward rocker-shaft; in rocking back and forth under the influence of the cam, it causes the wipers to engage the riders, thus lifting or lowering the free ends of the levers, and hence opening or closing the steam valves. The **after rocker-shaft** *g* carries the double **after rocker-arm** *i*, which is keyed to it. This after rocker-arm has two pins *i'* and *i"*, equidistant from the center of the after rocker-shaft and exactly opposite each other. The lower pin *i"* is made long enough to allow both the full-stroke reach rod and also a link *n* connecting it with the forward rocker-arm pin to be attachea to it. This link *n* has been omitted in view (*a*) in order to show more clearly the parts of the valve gear. In view (*b*) it has also been omitted in order to show the pins *h'* and *i"*. The **after exhaust crank** *k* is also keyed to the after rocker-shaft in the position shown. The **forward exhaust crank** *l* forms part of the casting on which the exhaust wipers are formed,

occupying the position shown in relation to the exhaust wipers. This crank *l* is connected to the crank *k* by the link *m*. For the purpose of clearly showing the essential parts of the valve gear, the reach rods and their attachments have been omitted in views (*a*), (*b*), and (*c*). Now, imagine that the pins *h'* and *i"* are connected by the **full-stroke link** *n* shown in view (*c*). Let the full-stroke reach rod be attached to the pin *i"*. Then the forward and after rocker-arms will move in unison with each other. Imagine that under the influence of the full-stroke cam the pins *i"* and *h'* move forwards, the piston having begun to move aft in the forward motion. Then, the wiper *d* moves upwards, and striking the rider *c* lifts the lever *a*, thus opening the forward steam valve. The wiper *d'* moves downwards and away from the after rider *c'*; hence the after steam valve remains closed. Now, it being necessary to open the after exhaust valve, a little thought will show that the after exhaust wiper *e'* must move upwards; that is, the steam and exhaust wipers must rotate in opposite directions. This is accomplished by the cranks *k* and *l* and the link *m*. As the pin *i"* moves forwards, the crank arm *k* moves upwards, rotating the exhaust wipers through the medium of crank arm *l* and link *m* in a direction opposite to that of the hands of a watch. As the piston nears the end of its stroke, the rocker-arms rock back towards the position shown in view (*a*). When the piston commences its forward stroke, the rocker-arms rock aft; this opens the after steam valve and forward exhaust valve.

6. In view (*d*) the reach rods and attachments are shown in the relative positions occupied when the crank is on either dead center and the engine is in the go-ahead motion following full stroke. In this view, *q* is the cut-off reach rod and *r* the full-stroke reach rod. The rod *r* is fastened to the **spider** *s*, which can be hooked over the lower or upper after rocker-arm pin, the inclined surfaces of the spider guiding the hook over the pins. The end of the cut-off reach rod *q* is hinged to one end of a **guiding link** *t*, which insures that the hook on the end of the rod *q* will engage the

forward rocker-arm pin. The lower end of the guiding link is hinged to the hooked end of the full-stroke link *n*. With the reach rods in the position shown, both the steam valves and exhaust valves move under the influence of the full-stroke cam. The cut-off reach-rod hook not being attached to anything but the free end of the guiding link, the link *t* simply rocks idly back and forth about the forward rocker-arm pin as a center.

7. When the boat is under way, the cut-off is placed on the engine; this is done simply by dropping the cut-off hook over the forward rocker-arm pin. In view (*e*) are shown the relative positions occupied by the different parts of the gear when the engine is in the go-ahead motion and cutting off, with the crank just passing one of the dead centers. The act of hooking on the cut-off reach rod automatically detaches the full-stroke link from the forward rocker-arm pin, thus allowing the two rocker-shafts to move independently. The exhaust wipers being loose on the forward rocker-shaft, the motion of the forward rocker-arm under the influence of the cut-off cam operates the steam wipers only. The exhaust wipers are operated by the full-stroke cam and from the after rocker-shaft.

8. The engine is reversed by the exceedingly simple method of hooking the full-stroke reach rod to the upper after rocker-arm pin, the cut-off reach rod having been first unhooked and the full-stroke link hooked over the forward rocker-arm pin. With the valve gear shown, it is impossible to cut off in the backing motion; in fact, the valves will not operate at the right time if the cut-off is left on while attempting to back. Shifting the full-stroke hook to the upper rocker-arm pin affects the motion of the gear as follows: Let the crank be on the forward dead center. Then, in order to back, the crank must run *over*, and the forward steam valve and after exhaust valve must be opened. The cam being fastened to the wheel shaft, the backward rotation of the cam moves the cam frame, and hence the upper rocker-arm pin, aft, while the lower after

rocker-arm pin and forward rocker-arm pin move forward, that is, in the right direction to open the forward steam valve and after exhaust valve.

9. In order to allow the cylinder to be warmed up, and also to facilitate the working of the engine by hand, a chain is attached to the free end of each steam lever in all types of lever engines. The two chains are joined a few feet above the levers to another chain, which passes over pulleys and leads to the starting platform or **foot board** where the engineer handling the engine is located. When about to reverse the engine, the engineer shuts off steam, then, by pulling the chain, lifts both steam levers, thus taking their weight off the wipers and allowing the full-stroke reach-rod hook to be readily shifted to the backing pin. The steam levers are now lowered into contact with the wipers and steam turned on. When waiting for a starting bell, the engines are kept warmed up and ready for starting by opening the steam valves on both ends of the cylinders and blowing steam through the cylinders; the valves are opened by raising the steam levers by means of the chains.

10. With the valve gear shown, which is the simplest type of gear, it is not advisable to give lead to the steam valves when following full stroke. If the full-stroke cam be advanced far enough to give lead to the steam valves in one motion, the steam valves will have negative lead when the engine is reversed, that is, they will not open until after the piston has completed part of its stroke. This is a defect inseparable from the employment of one full-stroke cam for actuating the valve gear in both motions. As the cut-off cam is used only when going ahead, it can be, and usually is, set to give lead to the steam valves. An early opening of the exhaust valves being desirable, it has been accomplished on the type of gear shown by **ridering** the exhaust-valve levers; that is, the riders have been made deep enough to allow both exhaust valves to open before the piston reaches the end of the stroke. While this method causes an early opening, it also causes a late closing of the exhaust

valves, so that at the beginning of the stroke both the steam valve and the exhaust valve on one end of the cylinder will be open and the steam will blow through into the exhaust pipe until the exhaust valve closes. That this must take place can readily be seen by referring to Fig. 2 (*a*). In this figure the valve gear is shown in the exact position it will occupy when the engine is on either dead center. The cams and the gear are supposed to be correctly adjusted, i. e., so that the proper steam and exhaust valves will open with the slightest movement of the crank past the dead centers. The exhaust wipers occupy the same position as the steam wipers *d* and *d'*. Now let the riders on the exhaust levers be deepened; this causes the free end of the exhaust levers to occupy a higher position, and consequently both exhaust valves will be open at the same time. Furthermore, when the cut-off cam is in use, the exhaust valves are operated by the full-stroke cam, and will open and close at the same time as when both the steam valves and the exhaust valves are worked by the full-stroke cam. Hence, when the cut-off cam is operating the steam valves, the ridering of the exhaust levers will also cause the blowing of live steam into the exhaust pipe, just the same as happens when following full stroke.

THE SWEENEY VALVE GEAR.

11. To overcome the difficulties mentioned in Art. **10,** the valve gear illustrated and described in Figs. 1 and 2 has been modified somewhat by Mr. John M. Sweeney, and quite a number of engines are now fitted with the **Sweeney valve gear.** The characteristic feature of this gear is the use of two full-stroke cams, one for going ahead and one for backing. The usual cut-off cam is provided for the go-ahead motion.

Each full-stroke cam is set so as to give the required lead in the motion the cam is intended for. The approximate position of the three cams in reference to each other and to the crank is shown in Fig. 3. In this figure, N_a is the go-ahead full-stroke cam, N_b is the backing full-stroke cam,

and M is the cut-off cam, which is used only in the go-ahead motion. The relative positions of the cams vary slightly

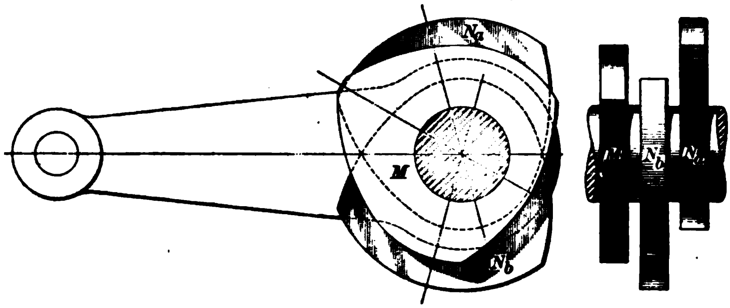
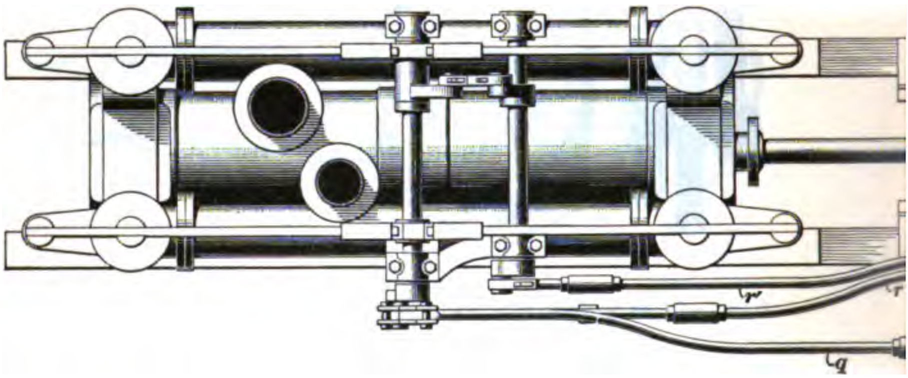
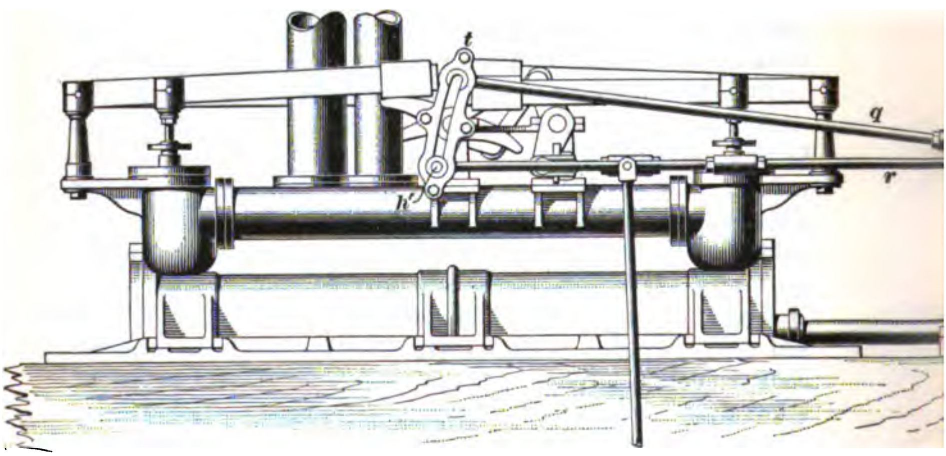


FIG. 3.

either way from the positions shown, according to the lead of the valves.

12. The valve gear is shown in detail in Fig. 4. In this figure the gear is shown in the position it occupies when the engines are going ahead and steam is following full stroke. For the purpose of showing the essential parts of the gear to as large a scale as feasible, the three cams, cam frames, etc., have been omitted. In the figure, R_a is the go-ahead full-stroke cam rod, R_b the backing full-stroke cam rod, and Q the cut-off cam rod. The forward ends of the full-stroke cam rods are pivoted to the two ends of the after guiding link U, which insures the hooking on of either rod to the pin v. This pin is rigidly fastened near the upper end of the vibrating arm V, which is free to turn about the shaft O. The cut-off cam rod Q is permanently attached to a pin v' on the vibrating arm V', which arm is keyed to the shaft O. This shaft is free to turn in its bearing. The cut-off reach rod q and the full-stroke reach rod r are hinged to pins in the upper ends of the vibrating arms V' and V, respectively. The forward ends of these two reach rods are pivoted to the two ends of the forward guiding link t; hooks are formed on the ends of the rods to allow either rod to be attached to the forward rocker-arm pin h'. In regard to the guiding links, it is well to bear in mind that their function


r
r
q


t
q
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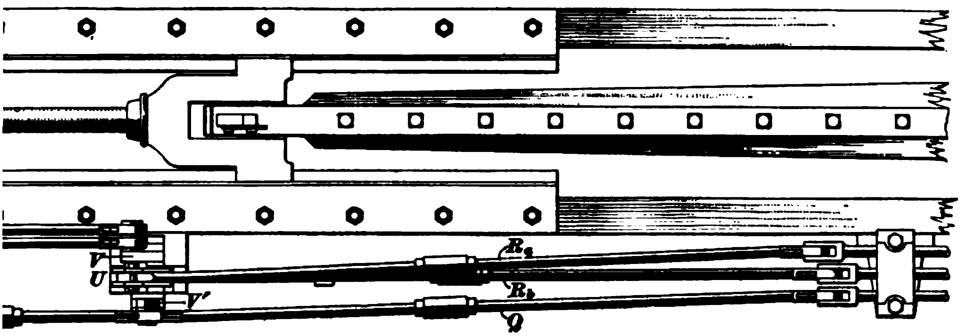
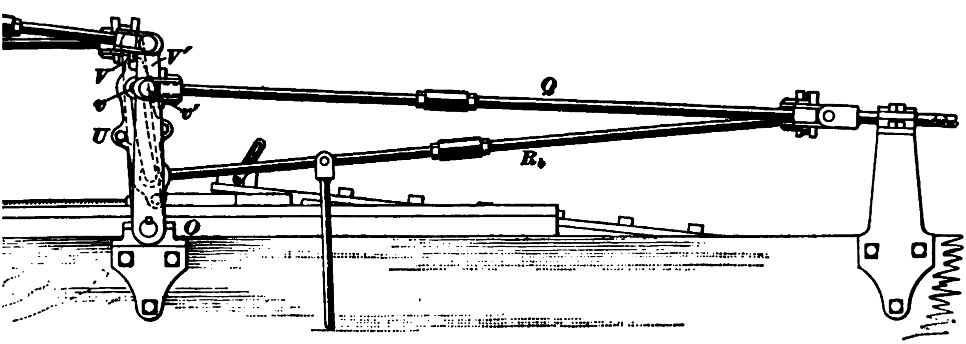
h'





. 4.

in no respect whatsoever is the same as that of the link in the link motion in common use; these links are not intended and can not be used for varying the cut-off, nor do they perform an essential duty in reversing the engine. Their sole function is to guide the hooks over the pins.

The pin in the upper end of the vibrating arm V is made long enough to carry one end of the exhaust reach rod r', which is hinged to the after rocker-arm pin and can not be detached. It will be observed that in this gear there is no link connecting the forward and after rocker-arm pins when following full stroke. However, the exhaust reach rod r' being attached to the vibrating arm V, which is operated only by either full-stroke cam, the exhaust valves are at all times and in either motion controlled solely by the full-stroke cams. The steam valves, however, can at will be placed under control of either one of the full-stroke cams or the cut-off cam when going ahead. The exhaust wipers are free to turn about the forward rocker-shaft, and are operated from the after rocker-shafts through the medium of two cranks and a connecting link, as was explained in connection with Fig. 2. The steam wipers are keyed to the forward rocker-shaft. With the gear in the position shown, any movement of the cut-off reach rod q induced by the vibrating of the arm V' under the influence of the cut-off cam simply causes the upper end of the link t to rock back and forth. Naturally this has no influence whatsoever upon the steam distribution, the opening and closing of the valves being dependent upon the motion of the forward rocker-arm pin. When it is desired to cut off, the cut-off hook is dropped over the forward rocker-arm pin. This automatically disengages the full-stroke hook from the pin; the lower end of the guiding link then vibrates back and forth as the full-stroke reach rod moves under the influence of the go-ahead full-stroke cam. Hence, the steam valves are now controlled entirely by the cut-off cam. When the engine is to be reversed, the first thing to be done is to hook the full-stroke reach rod to the forward rocker-arm pin. Then, the full-stroke backing cam rod R_b is moved

upwards until the hook engages the pin *v*. The upper end of the link *U* now freely rocks back and forth as the go-ahead cam rod moves under the influence of the cam, and the vibrating arm *V* is under the control of the backing cam. As a consequence, both the steam valves and the exhaust valves are also under the influence of the backing cam, and the engine will run in the backing motion as soon as the steam is turned on.

13. The gear just shown and explained gives an early exhaust opening and early exhaust closing, and also an early opening of the steam valves. Now, if the wipers for the steam and exhaust valves have the same shape, the steam valve on one end of the cylinder and the exhaust valve on the other end of the cylinder will open exactly at the same time, it being assumed that the different parts of the valve gear are correctly adjusted. But for smooth running of the engine, it is desirable that the steam lead be less than the lead of the exhaust valves; in other words, it is desirable that the exhaust valves open sooner than the steam valves. This has been accomplished in this gear by the simple expedient of making the steam wipers different in shape from the exhaust wipers, as is shown in Fig. 5.

14. In this figure, *d* and *d'* are the steam wipers keyed to the shaft *f*. The exhaust wipers *e* and *e'* are loose on this

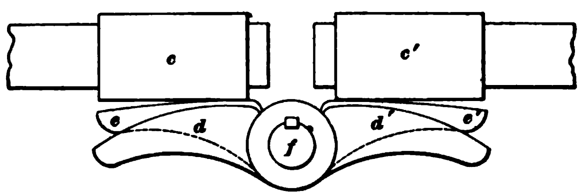


FIG. 5.

shaft. Both sets of wipers are shown in their neutral positions, which they will occupy when the cam frame is central in respect to the shaft. As shown in the illustration, the exhaust wipers are in contact with both riders; but the working face of the steam wipers has been curved downwards

so that there is some space between it and the corresponding steam rider. The effect of this change of shape is as follows: Let the exhaust wiper *e'* move upwards. The slightest upward motion opens the exhaust valve. But as soon as the exhaust wipers commence to move, the steam wipers move in an opposite direction; thus, the steam wiper *d* moves upwards. But owing to the space between its face and the rider *c*, the steam valve remains closed until the wiper engages the rider. This shows that the dropping of the steam-wiper faces below those of the exhaust wipers causes the exhaust valves to open before the steam valves open. The exhaust valves will close at the same part of the stroke on which they opened; likewise the steam valves when under the control of either of the full-stroke cams. When cutting off, the cut-off cam is set so as to give lead to the steam valves, which can be done, since the cut-off is used only in the go-ahead motion.

VARIABLE CUT-OFF ENGINES.

15. A **variable cut-off** engine is shown in Figs. 6 and 7. The valve gear is of the releasing type; that is, at a predetermined point of the stroke the steam valves are released from the levers and are closed by heavy helical springs. This particular type of variable cut-off is known as the **Cross cut-off** and also as the **California cut-off.** The releasing mechanism is shown to an enlarged scale in Fig. 6, and will be explained first, as a knowledge of its construction will facilitate a proper understanding of its operation. In the figure, *a* is one of the steam levers, hinged at *b* to its standard. The valve-stem head *c*, instead of being hinged to the lever, straddles it, as shown. A small steel roller *e* is placed inside of the upper end of the slotted head. A movable steel shoe *s* with an inclined end surface rests on top of the lever, and in the position shown is interposed between the roller *e* and the lever. The shoe is free to slide along the upper surface of the lever, being confined sideways by the guides *f* and *f'*, which are bolted to

both sides of the lever. The upper part *c'* of the valve-stem head is cylindrical and fits the cylinder *g*, which forms part of the standard *h*. This cylinder contains the helical spring *i*, tending continually to force the valve downwards. At the beginning of the stroke the lever *a* is moved upwards by the steam wiper; the shoe *s* being between the roller *e* and

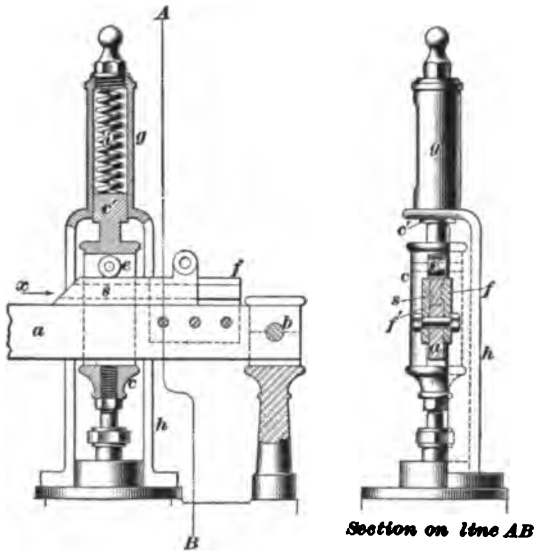


FIG. 6.

the lever, the valve is opened. But under the influence of its actuating mechanism, the shoe *s* slides in the direction of the arrow *x*; as soon as the roller passes the upper corner of the inclined end surface of the shoe, the valve-stem head, and hence the valve, is forced down by the spring and the steam port closed. It will thus be seen that the time at which cut-off takes place depends entirely upon the time at which the inclined surface of the shoe *s* passes under the roller.

16. In Fig. 7 the actuating mechanism is shown, the different parts of the valve gear being in the positions they will occupy when the crank is on the forward dead center. There are again four levers, which are operated by wipers

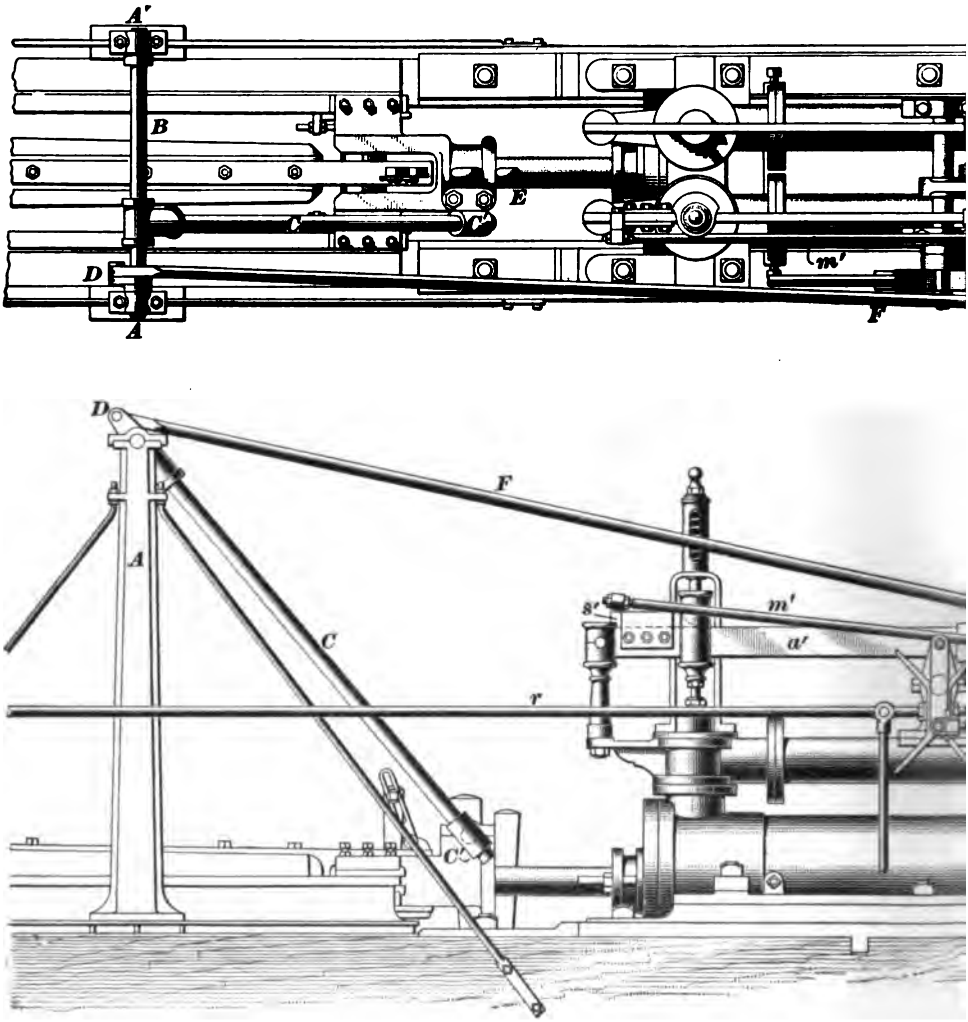
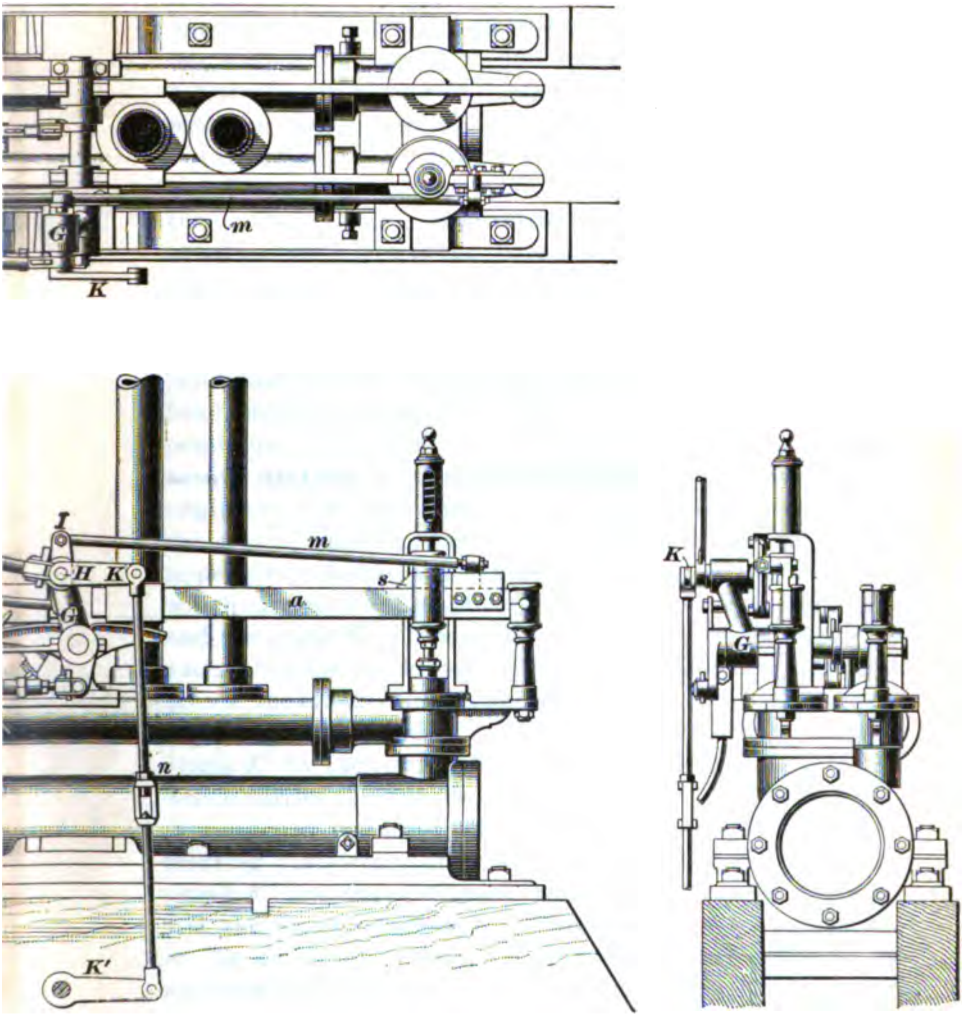


FIG.



7.

on the forward rocker-shaft, the wipers being operated from the after rocker-shaft. One full-stroke cam is employed for both motions, the engine being reversed by shifting the full-stroke hook from the lower after rocker-arm pin to the upper pin. Thus it is seen that if the cut-off mechanism be left out of consideration, the valve gear, when following full stroke, operates exactly as was explained in connection with the fixed cut-off engine shown in Figs. 1 and 2.

The construction of the cut-off actuating mechanism is as follows: The standards *A* and *A'* carry a shaft *B* free to turn in its bearings. A **pendulum rod** *C* and **pendulum crank** *D* are keyed to the shaft in line with each other. The lower end of the pendulum rod fits loosely in the sleeve *C'*, which is free to turn in a vertical plane in a bearing *E* forming part of the cross-head. This construction allows the pendulum rod to swing back and forth with the cross-head, sliding through the sleeve *C'*. The combination of pendulum rod and sleeve is usually spoken of as a **telescope motion** or **pendulum motion** by Western river engineers. A connecting-rod *F* connects the crank *D* with the arm *G*, which is loose on the forward rocker-shaft. The upper part of this arm forms a bearing for the shaft *H*, which carries on one end the double crank *I* and on the other end the crank *K*. These two cranks are at right angles to each other and are keyed rigidly to the shaft *H*. The two pins of the crank *I* are connected to the shoes *s* and *s'* by the adjusting rods *m* and *m'*. The crank *K* is connected to the crank *K'* by the rod *n*. The crank *K'* is keyed to its shaft, which carries the cut-off adjusting lever; this lever works in a notched quadrant and is located on the foot board or starting platform within easy reach of the engineer. The crank *K'* remains stationary while the engine is running. Let the crank commence the lower half of its revolution in the go-ahead motion. Then, the arm *G* being in its extreme after position, as shown, the shoe *s* is interposed between the roller in the forward steam-valve head and the forward steam lever. The full-stroke cam causes the lever to move upwards and the steam valve is opened, also the

after exhaust valve. But at the same time that the cross-head commences to move aft, the crank *G* moves forwards and carries with it the double crank *I*. Now, this crank *I* does *not* rotate while the arm *G* is swinging forwards or backwards, but keeps its angular position in respect to a vertical line throughout the whole range of movement of the arm *G*. As a consequence, the rods *m* and *m'* force the shoes *s* and *s'* forwards at the same speed and through the same distance as the center of the shaft *H*.

In order to be entirely accurate, it is well to mention that owing to the upper end of the rod *n* and owing to the center of the shaft *H* describing arcs during the movement of *G*, a very slight irregularity is introduced into the movement of the shoes considered in conjunction with the movement of the arm *G*. However, this irregularity is so small that we are safe in stating that for all practical purposes the movements of the shoes and the center of the shaft *H* are coincident.

The shoes moving forwards while the piston moves aft, the shoe *s'* is pulled in between the roller of the after steam valve and its lever. The shoe *s* is pushed forwards at the same time, and as soon as the roller passes the upper corner of the inclined face of the shoe, the spring above the valve-stem head returns the valve to its seat, thus cutting off the steam supply.

Bearing in mind that the movement of the shoes is always in a direction opposite to that of the piston, a little thought will show that the time at which cut-off will take place depends entirely upon the distance between the center of the shaft *H* and the upper corner of the inclined surface of the shoe. Now, if means are provided for varying this distance at will, the time of cut-off can be varied accordingly. The double crank *I*, the cranks *K* and *K'*, the rod *n*, and the cut-off lever with its quadrant serve this purpose. Let the cut-off lever be moved so that the crank *K* moves upwards. Then the upper pin of the double crank *I* moves aft and the lower pin forwards, pulling with them the rods *m* and *m'* and the shoes *s* and *s'*, thus bringing them nearer

to each other, or, in other words, shortening the distance from the upper corner of the inclined face of each shoe to the center of the shaft H by the same amount. Conversely, if the crank K is moved downwards, this distance is lengthened. If the rods m and m' are connected just the reverse way from that shown, that is, if the rod m' is connected to the upper pin and the rod m to the lower pin of I, a movement of the crank K will have just the opposite effect upon the time of cut-off from what it will have when the rods are connected as shown. The rods may be connected either way without affecting the operation of the cut-off mechanism beyond the fact that the cut-off lever must be moved to suit the method of connection.

From what has been explained here, it will be seen that *with the California cut-off, the farther the shoes are apart, the earlier cut-off will take place. Conversely, the nearer they are to each other, the later cut-off will occur.*

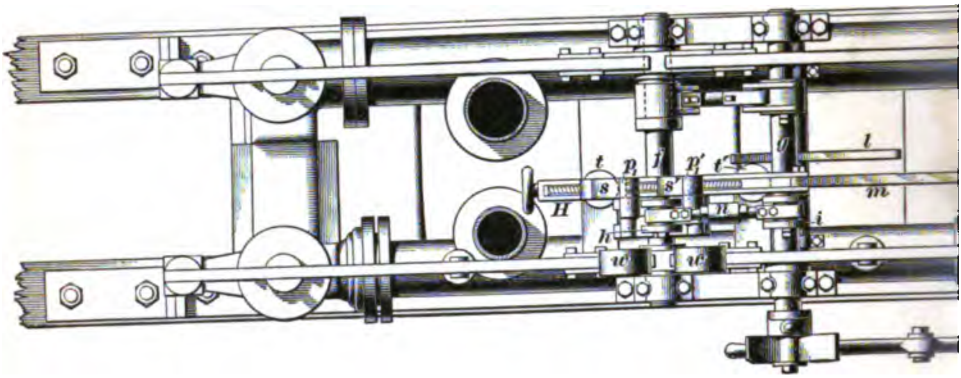
17. This cut-off mechanism will operate in either motion. It is also constructed by some builders to work with an eccentric instead of the telescope motion. In that case the eccentric is placed just about opposite the crank if the eccentric-rod is coupled direct to the arm G, i. e., without the intervention of a reversing rocker of the kind explained in conjunction with the steam distribution of a slide valve. *It is essential that the arm G move in a direction opposite to that of the piston.* If this is kept in mind, the proper eccentric position for a direct-connected eccentric-rod or with a direct rocker or reversing rocker can be readily found.

18. A cut-off gear of a somewhat different type is that known as the **Rees variable cut-off,** which is shown in Figs. 8 and 9. The engine has four independent poppet valves attached to levers; the valves are operated by wipers. As in the other engines described, the wipers are located on the forward rocker-shaft and operated from the after rocker-shaft. The exhaust wipers are loose on the forward rocker-shaft, while the steam wipers are keyed to it. The

exhaust wipers derive their motion from the after rocker-shaft through two cranks and a diagonal link, which imparts to them a motion opposite in direction to that of the steam wipers. The valve gear when following full stroke is operated by one full-stroke cam, which serves for both motions. The engine is reversed by shifting the cam-rod hook from the lower rocker-arm pin to the upper rocker-arm pin. When using the cut-off, the steam valves are opened by the full-stroke cam, but close under the action of the cut-off gear. The exhaust valves at all times are controlled by the full-stroke cam.

The Rees cut-off gear belongs to the same class as the California cut-off, in that it is a releasing gear; but while in the California cut-off gear the valves are released by being detached from the levers, they are released in the Rees gear by automatically detaching the steam wipers from the control of the full-stroke cam at the predetermined point of cut-off. The weight of the steam lever and of the attached valve then forces the wipers back to their mid-position, gravity thus closing the steam valves.

19. The cut-off mechanism is shown to an enlarged scale in Fig. 9. As a knowledge of its construction is necessary to understand its operation, we will explain it in detail. Like parts have been lettered alike, so the student may refer both to Figs. 8 and 9 in order to find the shape and relative positions of the various parts. An arm *i* is keyed to the after rocker-shaft *g*. This arm is connected by the link *n* with a loose arm *h* located on the forward rocker-shaft *f*. This loose arm, which is shown separately in Fig. 9 (*e*), is placed between the two halves of a clutch *c* keyed to the forward rocker-shaft *f*. Two views of this clutch are shown in Fig. 9 (*f*). The loose arm *h* is connected to and disconnected from the clutch by the two pawls *p* and *p'*. Both pawls have the same fulcrum, and each pawl is provided with a long projection, shown at p_1 and p_1'. Three views of one of the pawls are shown in Fig. 9 (*g*), which clearly show its shape. A slide *H* which carries the cut-off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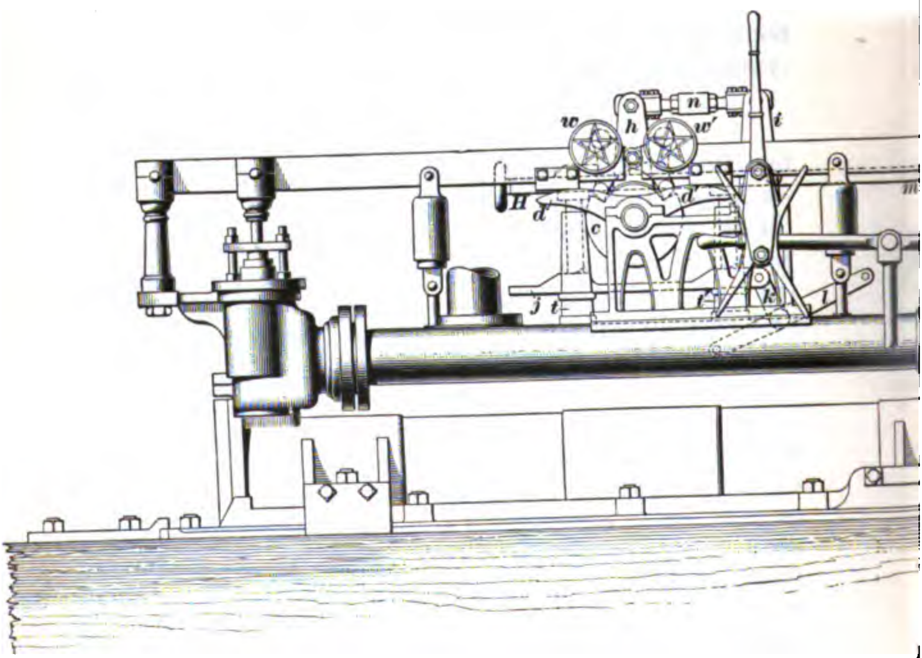
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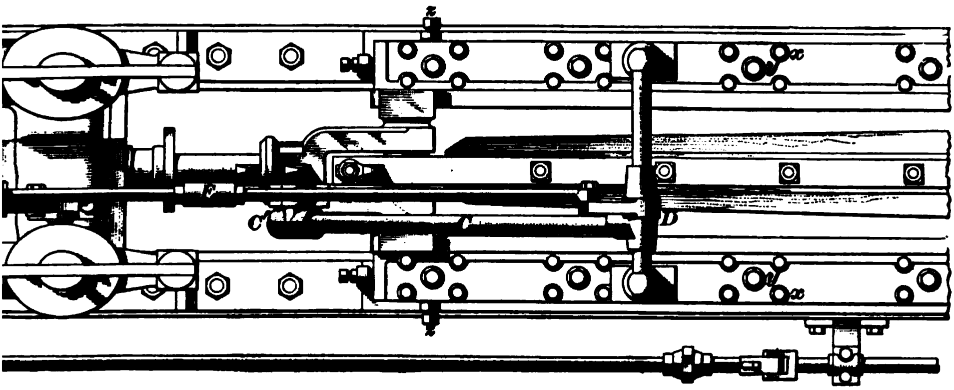
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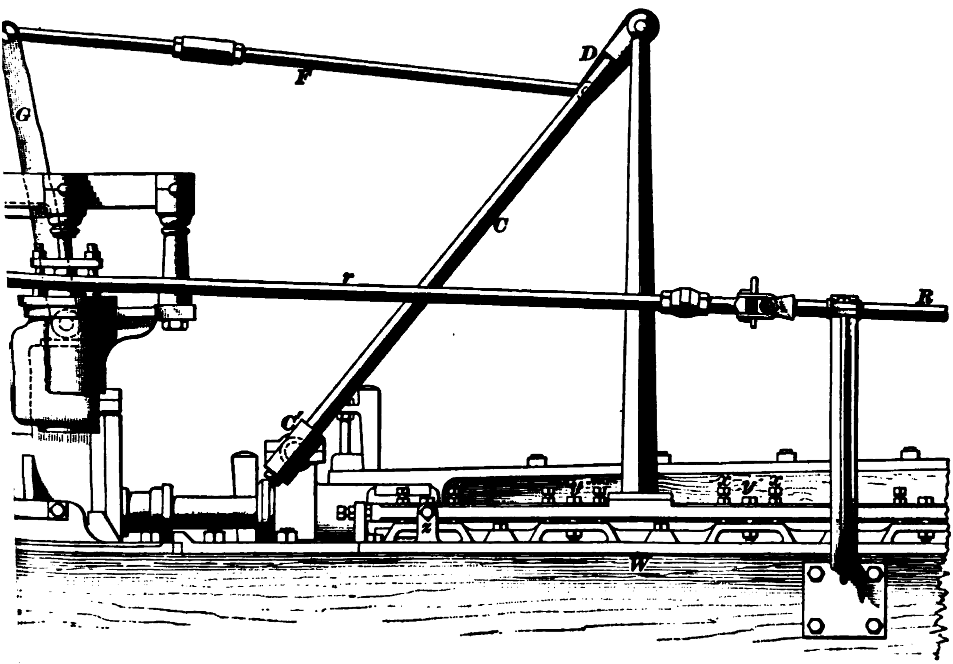
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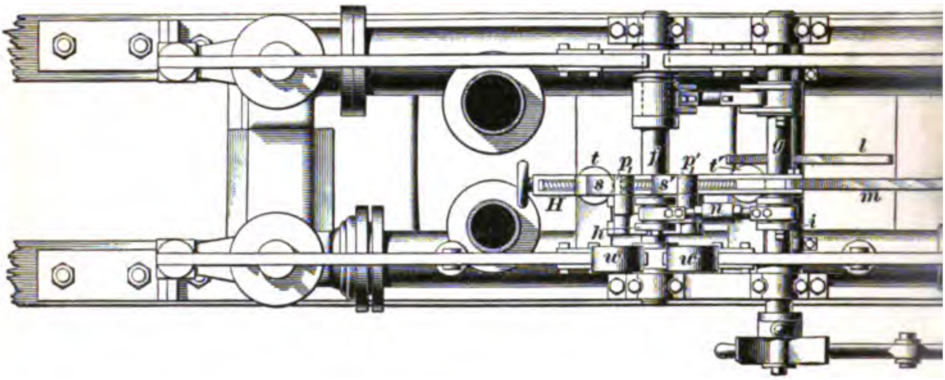
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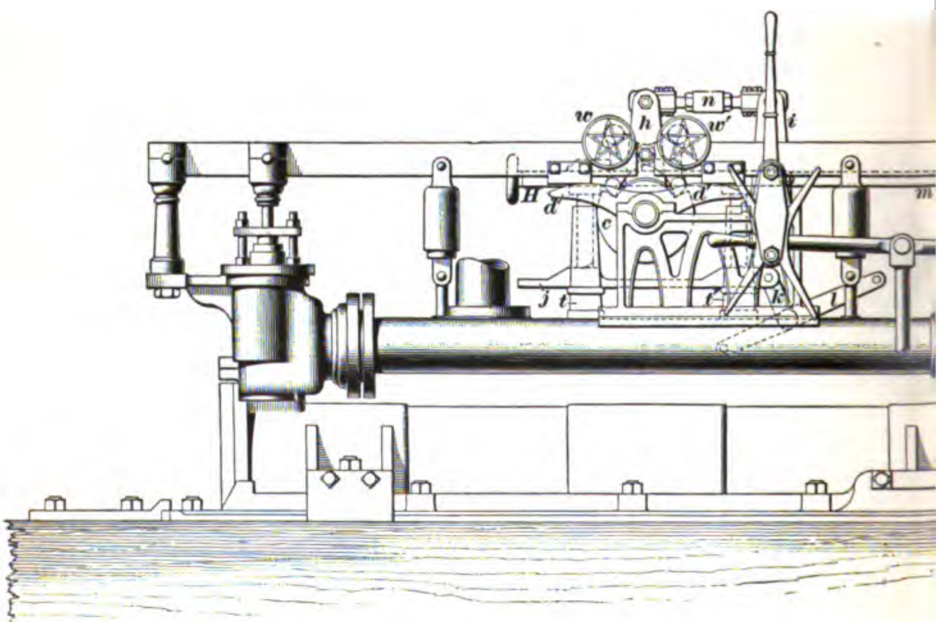
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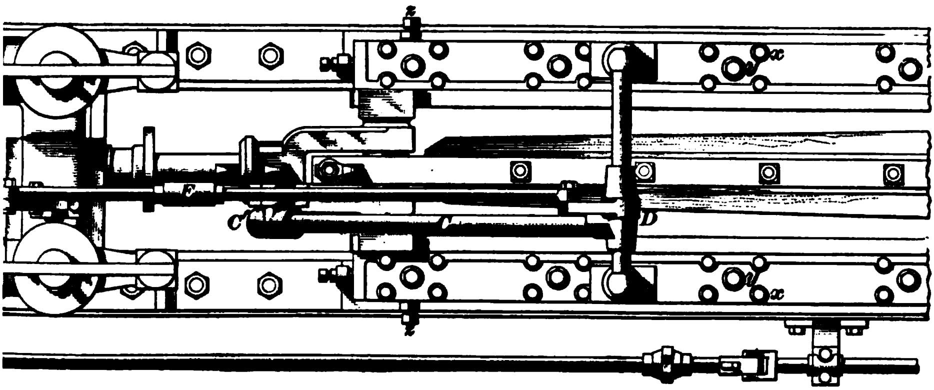

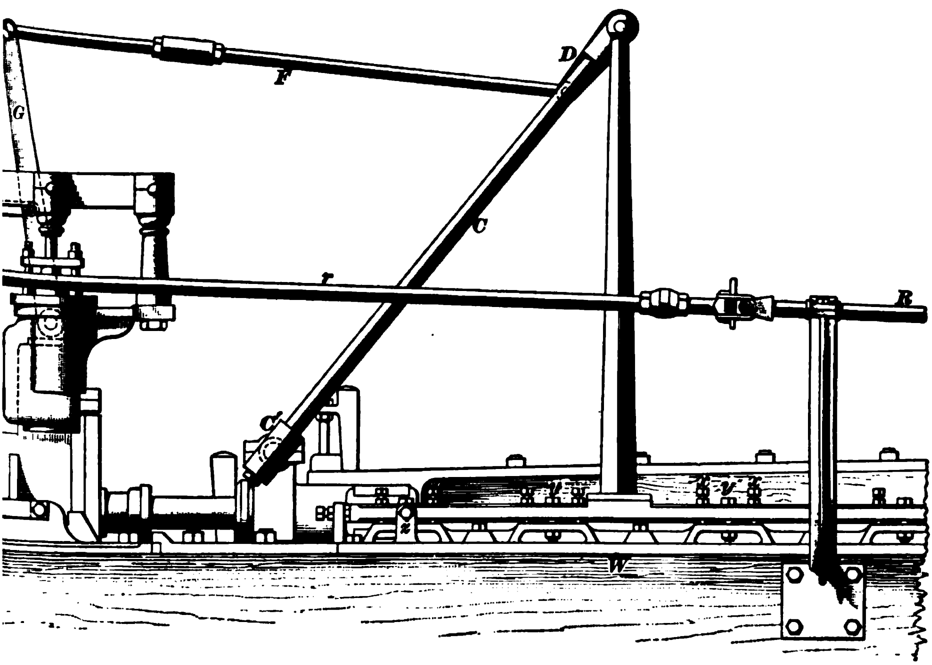

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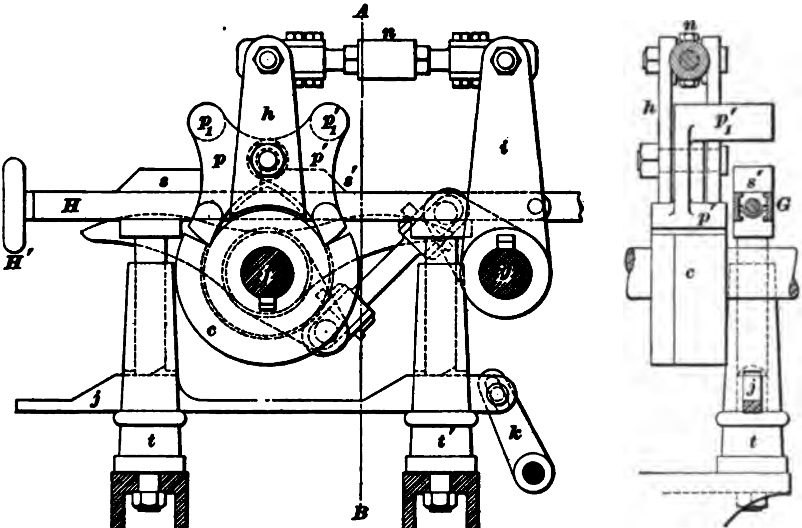
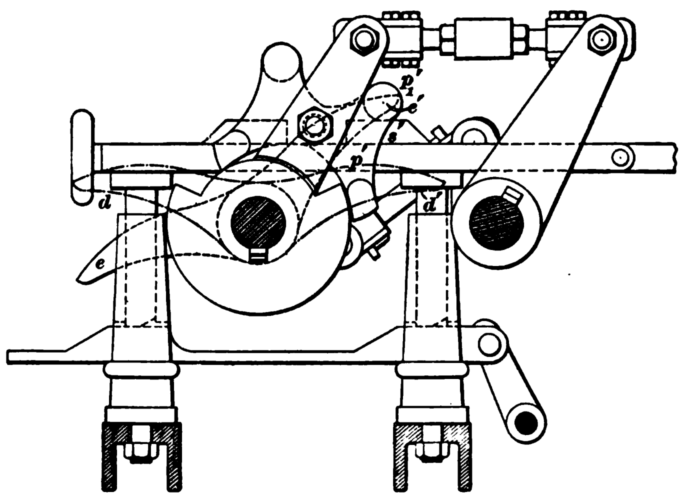


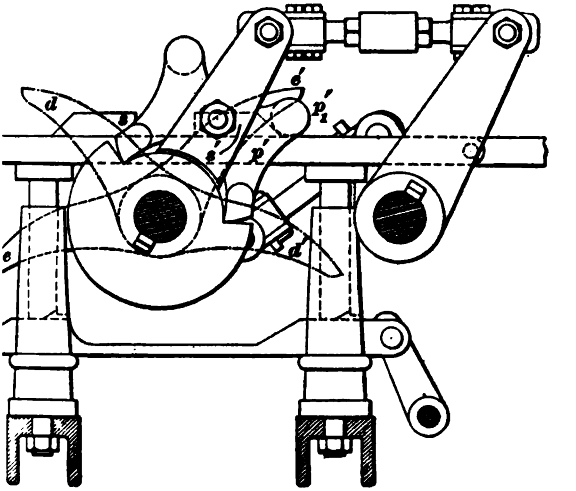
Section on line A.B.

(a)

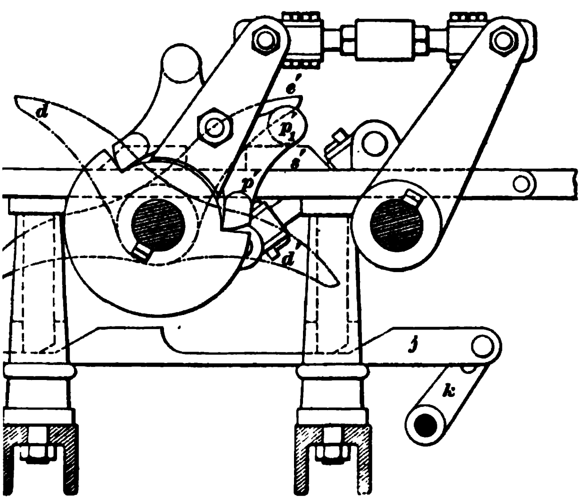


(c)

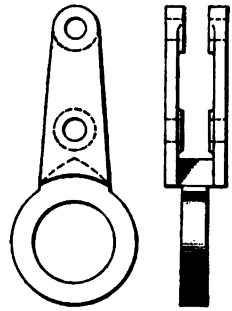

Fig



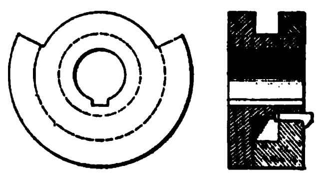
(b)



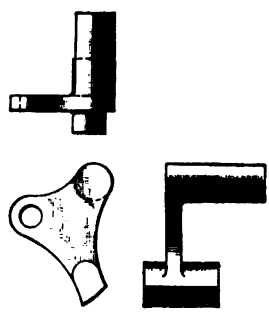
(d)



(e)



(f)



(g)

blocks *s* and *s'* lies alongside of the clutch; it is so mounted that it can slide in a fore-and-aft direction. This slide is carried on two plungers, free to slide vertically in the standards *t* and *t'*. The two plungers can be raised or lowered simultaneously by moving the wedge slide *j* forwards or aft. A crank *k* and lever *l* are provided for this purpose. The lever *l* is shown in Fig. 8. Ropes about ½ inch in diameter are fastened to both ends of this lever *l*, and are led over pulleys to the foot board, within convenient reach of the engineer. The purpose of raising and lowering the plungers, and hence the slide *H*, will appear later on. The slide *H* is moved in a fore-and-aft direction by the pendulum rod *C*, which slides in the sleeve *C'* pivoted to the cross-head, and the crank *D*, reach rod *F*, lever *G*, and link *m*. This pendulum arrangement gives to the slide, on a reduced scale, a motion corresponding to that of the piston. The direction of motion of the slide is always *in the same direction* as that of the piston. In Fig. 8 the different parts of the valve gear are shown in the position they occupy when the crank is on the forward dead center. In Fig. 9 (*a*) the cut-off mechanism is shown in the same position, but enlarged. The slide *H* is in its upper position. Now, imagine that the crank is just commencing the lower half of its revolution in the go-ahead motion. Remember that all stern-wheel and side-wheel horizontal direct-acting engines run *under* when the vessel is going ahead. Then the cam forces the cam frame forwards, and as the cam rod is connected to the lower rocker-arm pin, the arms *h* and *i* move in the direction of the hands of a clock towards the position shown in Fig. 9 (*b*). The pawl *p'* engages the clutch, and as both the clutch and the steam wipers *d* and *d'* are keyed to the same shaft, the forward steam wiper *d* goes up and opens the forward steam valve. At the same time the exhaust wipers *e* and *e'* rotate in the opposite direction; that is, the after exhaust wiper *e'* goes up and opens the after exhaust valve. When the arms *h* and *i* reach the position shown in Fig. 9 (*b*), those parts of the valve gear which are under the control of the full-stroke cam remain at rest, the cam being so shaped

that the valves are opened rapidly, kept wide open, and closed quickly at the end of the stroke. But, as previously explained, the slide *H* moves in the same direction as the piston. Hence the cut-off block s' will at some time reach the projection p_1' of the pawl p'. Then the inclined surface of the cut-off block forces the projection p_1' upwards as the block continues to move aft. The effect of this is to withdraw the pawl p' from the clutch. As soon as the clutch has been released from the pawl, the forward rocker-shaft and the steam wipers attached to it are free to turn, and do so under the influence of the weight of the forward steam lever and its valve and stem, closing the forward steam valve. To increase promptness of action, additional weights w, w' are placed on the steam levers. The exhaust valves being at all times under the control of the full-stroke cam, the after exhaust valve remains open, since the exhaust wipers retain their position. The relative positions of the various parts of the cut-off mechanism after cut-off has taken place are shown in Fig. 9 (*c*). The pawl p' is shown disengaged from the clutch; the projection p_1' rests on the upper surface of the block s', and as this surface is parallel to the line of motion of the slide *H*, the projection p_1' remains at rest while the slide *H* continues its motion. When the piston reaches a position near the end of its stroke, the cam on the shaft forces the cam frame aft, the arms *h* and *i* rock forwards, the exhaust wiper c' descends, and the after exhaust valve closes. When the crank reaches the after dead center, the pawl p' has dropped into the clutch again by its own weight. The pawl p is now in contact with the forward notch of the clutch, and any further forward movement of the arms *h* and *i* opens the after steam valve and forward exhaust valve. In due time the cut-off block s engages the projection p_1 and disengages the pawl p from the clutch. Cut-off then takes place.

Now, the movement of the blocks being coincident with that of the piston, it can readily be seen that the sooner the blocks engage the projections of the pawls, the sooner cut-off will occur. Conversely, the later they disengage the

pawls, the later cut-off will take place. From this we learn the rule:

To shorten the cut-off in the Rees mechanism, lengthen the distance between the cut-off blocks. To lengthen the cut-off, shorten the distance between the blocks.

To allow this to be readily done, the blocks are mounted on a right and left handed screw contained in the slide *H*. This screw is provided with a hand wheel *H'*.

20. In order to have the engine under full control when making or leaving landings, etc., the engineer must be able to let steam follow full stroke. This he can readily do by lowering the slide *H* by means of the wedge slide *j*, crank *k*, and lever *l*, as previously explained. The lowering of the slide *H* places the cut-off blocks below the positions occupied by the projections on the pawls when the valves are open; hence, as they now can not disengage the pawls from the clutch, all the valves are operated entirely by the full-stroke cam. Fig. 9 (*d*) shows the position of cut-off mechanism when following full stroke. The forward steam valve and after exhaust valve are wide open; the cut-off blocks are lowered out of the way of the pawl projections, and as they move aft, simply pass beneath the projection p_1'.

The construction of the guides is quite elaborate, and allows them to be lined up very accurately. They are bolted to a bed-plate *W* and are provided with a number of set-screws, as *x*, *x*, which can be locked by locknuts. By means of these set-screws, the guides can be accurately leveled; the guides are then tightened up by screwing up the holding-down bolts, as *y*, *y*. To line the guides sideways, set-screws *z*, *z* are provided.

THE TWO-VALVE ENGINE.

21. On the upper Mississippi and its tributaries a class of engine which differs considerably from those previously described is often found. In this class of engine two valves are employed. One of these, which is known as the **main**

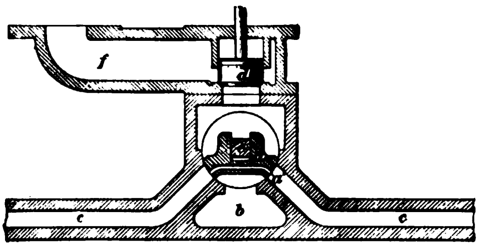
valve, serves to admit and exhaust the steam from the cylinder. As usually constructed, it allows steam to follow almost full stroke. It may be either an ordinary slide valve or a rotary valve similar to that employed in a Corliss engine. The other valve, which is known as the **cut-off valve,** is entirely independent of the main valve. It serves to cut off the steam supply from the steam chest at the point of cut-off determined upon. This valve is usually a poppet valve.

22. A two-valve engine may belong to either the fixed cut-off type or variable cut-off type of engine.

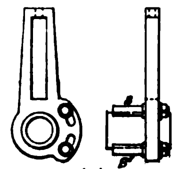
A two-valve engine of the latter type, as built by the D. M. Swain Engine Works, Stillwater, Minnesota, is shown in Fig. 10. The main valve *a*, which is shown in section in Fig. 10 (*a*), is a rotary or rocking valve. On being rocked to and fro by the valve gear, it admits steam to one of the steam ports *c*, *c*, and at the same time connects the opposite steam port with the exhaust port *b*. It differs in its operation from the ordinary **D** slide valve only in the fact that instead of covering and uncovering the ports by sliding, it does so by rotation about its center. As clearly shown, the valve is slotted to receive the rectangular valve stem *e*. This method of joining the valve and stem allows the valve to adjust itself to its seat.

The cut-off valve *d* is located directly above the main valve, and controls the only steam inlet to the main-valve chest. This cut-off valve is a single-seated balanced poppet valve. As shown in the figure, it works in a cylinder formed in the cover; a packing ring is used to make it steam tight. The main steam pipe is attached to the nozzle *f*.

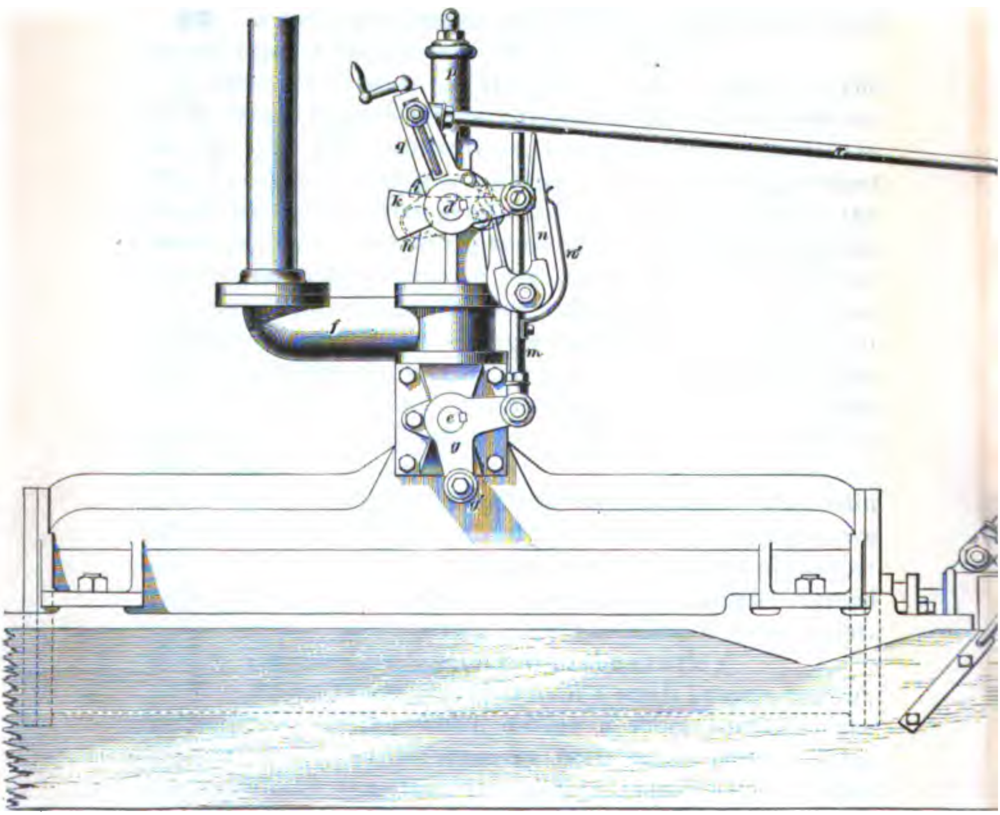
The rotary valve is provided with a small by-pass port *a'*, shown in Fig. 10 (*a*), which during a short period in the rocking of the valve connects both steam ports. This by-pass port is so located that shortly before exhaust takes place, it allows steam from the side of the piston which is about to exhaust to flow to the other side of the piston and fill the clearance space.



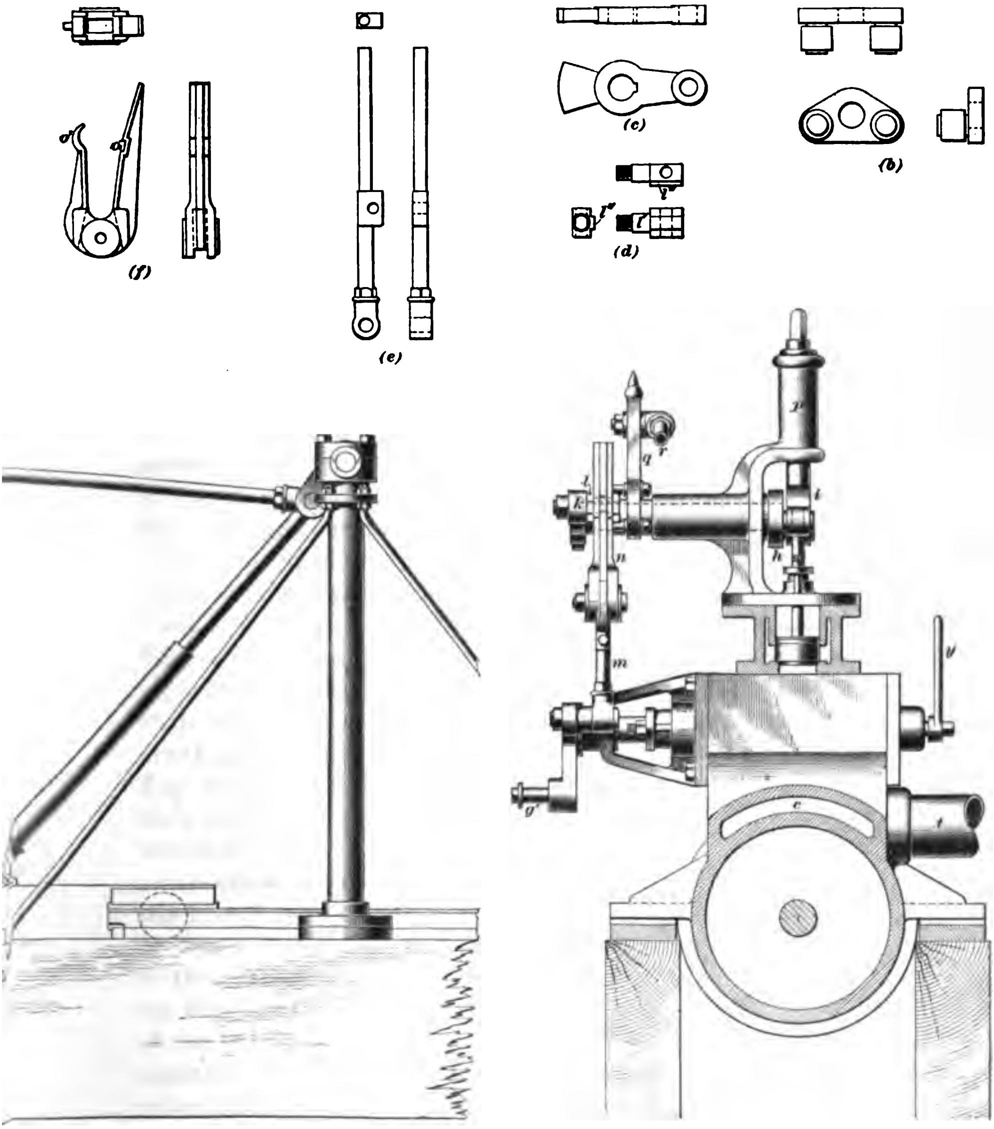
(a)



(g)



FI



10.

The main valve is operated by a cam and cam rod, there being a separate cam for each motion. As previously described in connection with the lever type of engine, the use of a separate cam for each motion allows lead to be given to the valve, thus giving an early steam opening and also an early exhaust opening. This naturally means an early exhaust closure and consequent cushioning of the piston. The two cam rods are hinged to a guiding link sliding over a link block pivoted to the pin *g'* of the bell-crank *g*. This bell-crank is keyed to the stem of the main valve. With the link down, the pin *g'*, and hence the main valve, is entirely under the control of the go-ahead cam. With the link up, the backing cam operates the valve. This link does not serve the same purpose as the link of the Stephenson link motion, viz., the varying of the cut-off, but is merely intended to guide either cam rod into its working position. The link and cam rods have been omitted in the illustration.

The cut-off mechanism is operated from the cross-head by a pendulum motion. The cut-off valve is raised by rollers carried on the end of the cross-arm *h*, which engage the head *i* of the cut-off valve stem. This cross-arm is shown separately in Fig. 10 (*b*). It is fastened to the rocker-shaft *d'*, to the other end of which the counterbalanced crank arm *k* is keyed. This crank arm is shown in detail in Fig. 10 (*c*). The **cut-off block** *l*, three views of which are shown in Fig. 10 (*d*), has a cylindrical shank *l'*, by virtue of which it is free to turn in the hole in the crank arm. The **crab-claw carrying rod** *m* passes through a hole in the block, and is free to slide through it. For a detail drawing of this rod, see Fig. 10 (*e*). The **crab claw** *n* is pivoted to the crab-claw carrying rod. It has a notch *o* in its face—see Fig. 10 (*f*)—which fits over the nose *l''*—see Fig. 10 (*d*)—of the cut-off block. The crab claw and cut-off block are held together by the spring *n'*. It is thus seen that the cut-off valve and the main valve are connected together when the crab claw engages the cut-off block. As soon as the crab claw is unhooked from the cut-off block, the cut-off valve is removed from the control of the main valve, and returns to

its seat, thus cutting off the steam supply from the main valve chest. In order to return the valve, a spiral spring is placed in the cylinder *p*; this spring acts upon the upper face of the cut-off valve stem, which is enlarged and extended into the cylinder. For the purpose of disengaging the crab claw, a cut-off rocker-arm *q*, shown in detail in Fig. 10 (*g*), is provided. This rocker-arm is loose on the rocker-shaft, and connected by the rod *r* to the pendulum motion. It is thus rocked to and fro by the movement of the cross-head. The rocker-arm is provided with two studs *s* and *s'*—see Fig. 10 (*g*)—which at some time during the rocking of the rocker-arm engage the nose *o'*—see Fig. 10 (*f*)—of the crab claw and force the latter away from the cut-off block, thus releasing the cut-off valve.

23. The operation of the valve gear is as follows: With the crank just passing the forward dead center and the cross-head just about to move aft, the different parts of the valve gear occupy the positions shown in the illustration. The valve being set to give lead, the forward steam port is partially open; the after steam port connects with the exhaust port and exhaust pipe *t*. The crab claw and cut-off block being engaged, the cross-arm *h* is tilted up slightly and has lifted the cut-off valve. As the cross-head moves aft, the pin *g'* also moves aft, being constrained to do so by the cam on the main shaft. The crab-claw carrying rod moves upwards, the cross-arm *h* is tilted up farther, and hence the cut-off valve and also the main valve open their respective ports. When opened to their full extent, the valves and main-valve operating mechanism remain stationary. But the rocker-arm *q* continues to move in the same direction as the cross-head, its direction of rotation being opposite to that in which the crank arm and valves have rotated. After a time, depending upon the speed with which it rocks, its upper stud engages the nose of the crab claw, disengages the crab claw from the cut-off block, and thus releases the cut-off valve. Steam is now shut off from the main valve and expansion begins. The main valve remains

in its position until near the end of the stroke, when it rocks back so as to place the forward steam port in connection with the exhaust port. On its way towards this position, it will for a short period occupy the position shown in Fig. 10 (*a*), connecting both ends of the cylinder by the by-pass port *a'*, whereby the clearance in the after end of the cylinder is filled before fresh steam is admitted. The crab-claw carrying rod *m* descends at the same time, and shortly before the crank reaches the after dead center, the crab claw hooks over the cut-off block again, and the main valve and cut-off valve are connected together once more. As stated before, the time at which cut-off takes place depends upon the speed with which the rocker-arm *q* rocks. Evidently, the faster the rocking, the sooner the studs will engage the nose of the crab claw, and *vice versa*. Hence, if means for varying at will the speed of rocking are provided, the cut-off can readily be varied. This is done by the simple expedient of attaching the rod *r* to the rocker-arm *q* in such a manner that the point of attachment can be moved towards or from the center about which the rocker-arm turns. *The nearer the point of attachment is to this center, the faster the rocker-arm will move and the earlier cut-off will occur; conversely, the farther away, the later the cut-off.*

24. An attachment is provided by which the main valve can be lifted off its seat to allow steam to be blown through the cylinder to warm it up or to relieve the boilers. Giving the handle *y* a quarter turn raises an eccentric inside of the valve chest. This eccentric engages a projection on the main valve and thus lifts it off its seat.

CAMS.

25. In order to produce a quick opening and closing of the valves, cams are universally employed on the lever type of steam engine, and occasionally for other types. As the number of revolutions per minute is very low, rarely exceeding twenty revolutions, they answer very well indeed. Inasmuch as landings have to be made very frequently, it is

essential that the engines be under perfect control of the engineer and respond promptly in either motion to the opening of the throttle. Owing to the rapid opening of the steam valves produced by the cam, the engines can be started without trouble when close to either dead center, as almost the full boiler pressure can be thrown instantly on the piston.

26. Cams for operating the valves of the lever engine differ considerably in shape, according to what service they are to perform. They may be divided into two classes, viz., "full-stroke cams" and "cut-off cams."

27. A full-stroke cam is required to quickly open the steam valve (and exhaust valve on the opposite side) as soon as the crank passes one of the dead centers. It must then hold the valves open until the crank has nearly reached the opposite dead center, when it must commence to close the valves, closing them entirely by the time the crank is on the dead center and the piston at the end of its stroke.

28. A cut-off cam must open the steam valves at the beginning of the stroke; hold them open and then close them rapidly and entirely as soon as the piston reaches the point at which cut-off is to take place.

29. It will thus be seen that while a full-stroke cam is designed to operate both the steam and exhaust valves, a cut-off cam is only intended, and can only be used, for operating the steam valves. When the cut-off cam is in use, the exhaust valves are operated by the full-stroke cam, the valve gear being so constructed that the act of bringing the steam valves under the control of the cut-off cam automatically releases them from the control of the full-stroke cam.

30. The construction of a full-stroke cam, and the cam frame through which the motion of the cam is transmitted to the rocker-arms, wipers, levers, and finally the valves, is shown in Fig. 11.

The cam *a* is fastened to the shaft by bolts passing through the oblong holes in the hub into a flange on the shaft. The

oblong holes allow the cam to be shifted readily for adjustment. While the cam shown is solid, they are more frequently made in two halves bolted together, thus allowing the cam to be removed and replaced without the necessity of taking the shaft from the bearings. The cam is enclosed in the cast-iron cam frame *b b'*; the two parts of the frame are bolted together by the through bolts *c* and *c'*, which are provided with nuts placed inside and outside of the upper and lower lugs of the cam frame. By means of these bolts and nuts, the distance between the working faces b_1 and b_2 can be regulated to a nicety. The cam frame slides in bearings fastened to the main bearing. The cam rod leading to

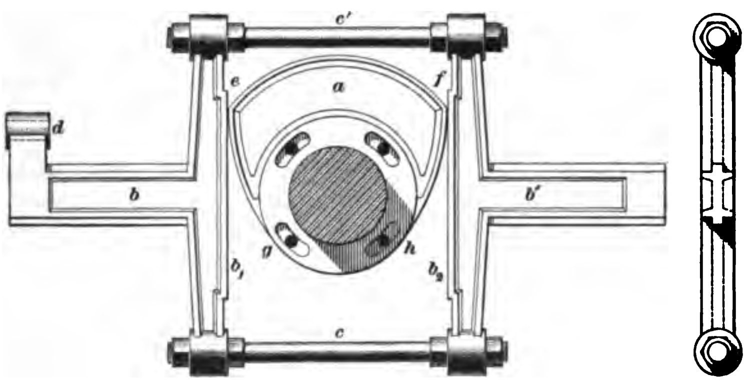


FIG. 11.

the rocker-arm is passed through the hole in the lug *d*; the cam rod is provided with two nuts, placed one on each side of the lug, for the purpose of adjusting the length of the cam rod.

Whenever the term *concentric arc* is used in this discussion, it means that the center from which the arc is described coincides with the center of the shaft. If the center of the arc does not coincide with the center of the shaft, the arc is *eccentric.*

In the cam the boundary lines are invariably arcs of circles. The arcs *e f* and *g h* are concentric. When these two arcs are in contact with the working faces of the

cam frame, the frame remains at rest; but as soon as the arcs *e g* and *f h*, which are eccentric to the shaft, come in contact with the frame, the latter is set in motion, and continues to move until the concentric arcs engage the frame again.

31. The action of the full-stroke cam is shown in diagrammatic form in Fig. 12. Before discussing the action, attention is called to the fact that the cylinder of the engine is *forward* and the crank *aft*. This statement applies both to side-wheel and stern-wheel steamboats. In consequence of this position of the engine, it runs *under* when going ahead. In Fig. 12 (*a*) the crank is shown on the forward dead center. The cam frame represented by the lines *a a'* and *b b'* is in its mid-position; that is, its working faces (see b_1 and b_2, Fig. 11) are equidistant from the center of the

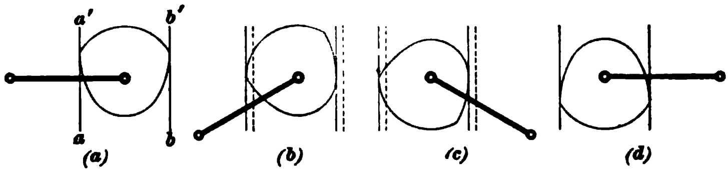


FIG. 12.

shaft. As the crank moves ahead towards the position it occupies in Fig. 12 (*b*), the corner *e* of the cam (see Fig. 11) drives the cam frame forward, and continues to do so until the crank reaches the position shown in Fig. 12 (*b*). The frame has then reached its extreme forward position, its displacement being indicated by the dotted lines, which represent the cam-frame position when the crank is on the dead center. With the frame in the forward position, the forward steam valve and after exhaust valve are opened to their full extent. While the crank moves towards the position shown in Fig. 12 (*c*), the frame remains at rest, since the concentric arcs *e f* and *g h* (see Fig. 11) are then in contact with the working faces of the frame. In consequence thereof, the forward steam valve and after exhaust valve remain wide open. As soon as the crank reaches the position shown in Fig. 12 (*c*), the point *g* of the eccentric arc *g e*

(see Fig. 11) bears against the after working face of the cam frame. Now, as the crank continues to move towards the after dead center, the arc *g e* forces the cam frame aft; as soon as the cam frame moves aft, the forward steam valve and after exhaust valve commence to close. They have closed entirely by the time the crank reaches the position shown in Fig. 12 (*d*), as then the cam frame is once more in its mid-position. The crank in moving through the upper half of its revolution causes the cam to force the cam frame to its extreme after position, thus opening wide the after steam valve and forward exhaust valve. These are then held open while the concentric arcs of the cam are in contact with the frame, and commence to close when the eccentric arcs force the cam frame forward, being fully closed the moment the crank reaches the forward dead center.

32. A cut-off cam designed to cut off at half stroke is shown in Fig. 13. In this cam, the arcs *h a*, *b c*, *d e*, and *f g* are concentric with the center of the shaft. The arcs *a b*, *c d*, *e f*, and *g h* are eccentric, and in pressing against the cam frame cause it to move.

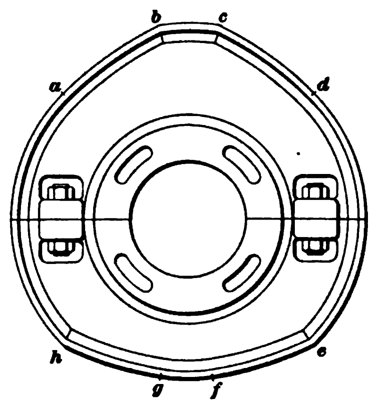
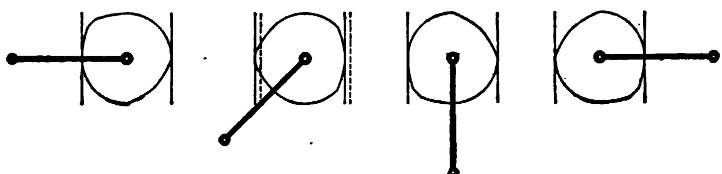


FIG. 13.

33. The action of the cam is shown in diagrammatic form in Fig. 14. With the crank on the forward dead center, the eccentric arc *a b* (see Fig. 13) is about to engage the cam frame represented by the vertical lines in Fig. 14. In passing from the dead-center position shown in Fig. 14 (*a*) to that shown in Fig. 14 (*b*), the cam frame is forced to its extreme forward position, its original position being shown by dotted lines. With the cam frame in this position, the forward steam valve is wide open, and remains so while the

concentric arcs *b c* and *f g* (see Fig. 13) are in contact with the frame. As soon as the point *g* of the eccentric arc *g h* reaches the after face of the cam frame, the latter is about to move aft. The crank and cam, in continuing their motion, force the cam frame aft to its mid-position, which position with a cam designed for cutting off at half stroke is reached when the crank has completed one-half of a half revolution; that is, neglecting the effect of the angularity of the connecting-rod, when the piston has completed one-half of its stroke. The cam frame in moving aft towards its mid-position, and through the action of the valve gear, allows



(a) (b) (c) (d)

FIG. 14.

the forward steam valve to close. The valve is fully closed the moment the cam frame is in its mid-position, and inasmuch as from now on the concentric arcs *a h* and *d e* (see Fig. 13) are in contact with the cam frame, the latter remains at rest while the piston is completing its stroke. As soon as the crank reaches the after dead center, as shown in Fig. 14 (*d*), the cam is about to force the cam frame to its extreme after position. The crank continuing the upper half of its revolution, the cam frame moves aft, opening the after steam valve, holding it open, and then closing it by the time the piston is at half stroke. The cam frame is now in its neutral position again, and remains at rest until the crank passes the forward dead center.

34. From the foregoing, it will be clear that the valves will move only when the cam frame moves, and of course remain at rest, either wide open or fully closed, whenever the cam frame is at rest. Bearing this in mind will greatly assist the student in arriving at a full understanding of the methods of laying out cams.

LAYING OUT CAMS.

35. Before we can proceed to lay out either a cut-off or a full-stroke cam, several data must be known. In the case of a full-stroke cam, we must know what distance the cam frame must move from its mid-position in order to fully open the valves. In the case of a cut-off cam, it must in addition be known at what point of the stroke steam is to be cut off, as a different point of cut-off requires a different shape of cam.

In order that there may be no misunderstanding on the part of the student, whenever hereafter the word **throw** is mentioned in connection with a cam, it is taken to mean the distance it moves the cam frame from its mid-position towards its extreme position, either forwards or aft. The student will do well to note the difference in the meaning of the term *throw* when applied to a cam and an eccentric; in the case of an eccentric, the term *throw* meaning twice the eccentricity, or if the eccentric be imagined to be enclosed in a cam frame, it would mean the distance moved by the cam frame from one extreme position to the other.

Whenever the term **size** is applied to a cam, it is understood to be equal to the diameter of a circle tangent to both working faces of the cam frame, diminished by the working clearance. Generally speaking, there is a clearance of from one-sixteenth to one-eighth of an inch between the cam and its frame, in order to allow for any slight deviation from the true shape of the cam.

36. No general rules can be laid down by which to figure out the proper throw of a cam for an engine. The data governing the throw are: the length of the rocker-arm, the length and shape of the wipers, the distance from the fulcrum of the lever to the valve stem, the distance from the fulcrum to the rider, the shape of the rider, and the required lift of the valve. The most practical way of determining what throw is required is to make a scale drawing, to as large a scale as possible, of the lever, rider, valve stem and valve, wiper, and rocker-arm when the valve is fully closed

and the rocker-arm in its mid-position. Then, if another drawing be made showing the valve opened the required amount, a comparison of the two drawings will show the distance the rocker-arm pin has moved from its mid-position in order to open the valve the required amount. If the cam rod connects directly to the rocker-arm pin, this distance equals the required throw. In some cases, however, devices are used which give a greater or smaller motion to the rocker-arm pin than that due to the motion of the cam frame under the influence of the cam. If such a device is used, the ratio by which it increases or decreases the motion of the cam frame must be taken in account. Such a device is the vibrating arm shown in connection with the Sweeney engine.

37. The rapidity with which a cam moves its frame to open or close the valves is greatly influenced by its size in relation to the throw, as will appear later on. In this respect, a cam differs essentially from the eccentric. In the latter, the eccentricity remaining constant, a change in the diameter of the eccentric sheave does not influence the movement of the valve in the least.

38. Laying Out a Full-Stroke Cam.—Given the throw and size of the cam, with the point *o*, Fig. 15 (*a*), as a center, draw a circle *f h* equal to the size of the cam. Through *o* draw the vertical center line *b h* and the horizontal center line *r s*. Then, parallel to the vertical center line and tangent to the circle *f h*, draw the lines *i j* and *k l*. From the point of intersection *f* of the vertical center line and the circle *f h* lay off upwards and on the vertical center line the distance *f b* equal to the throw. Now, with *o* as a center and a radius *o b*, describe an arc *a b c*, intersecting the vertical lines *i j* and *k l* at *a* and *c*, respectively. From the points *a* and *c* draw indefinite lines *a d* and *c e* passing through the center *o*. Then, with the points *a* and *c* as centers, and a radius equal to the diameter of the circle *f h*, describe the arcs *c d* and *a e*. Next, with *o* as a center and a radius *o d*, draw the arc *d g e*. If the cam is carefully drawn, the distance *g h* is exactly equal to *b f*.

39. Imagine the crank to occupy the position *o s*, that is, be on the after dead center. Let the crank move in the direction of the hands of a watch. Then, the line *k l* representing the after working face of the cam frame, the point *c* will force the cam frame aft until the point *c* reaches the line *o s*. In order to move the cam frame from its mid-position

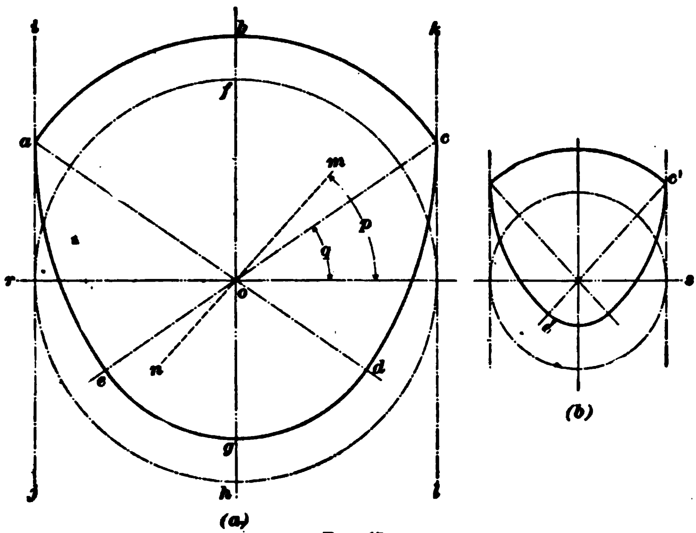


FIG. 15.

to its extreme position, the point *c* moves through an arc corresponding to an angle *q*. Now, evidently the smaller the angle *q*, the quicker will be the movement of the cam frame, and hence the quicker the valves will be opened. Conversely, the larger the angle *q*, the slower the opening of the valves.

40. We are now ready to investigate the influence the size of the cam exerts upon the rapidity of opening and closing of the valves.

In Fig. 15 (*b*) is shown a full-stroke cam having the same throw as the one shown in Fig. 15 (*a*). This cam is laid out by the same method as the large cam. Through the point *o*, Fig. 15 (*a*), draw the line *m n* parallel to *c′ e′*. Then, the angle *p* is the angle through which the point *c′* moves in order to open the valves entirely. But the angle *p* is larger

than the angle q; hence the larger cam will give the quickest opening of the valves.

From this we may draw the following conclusion: *The larger the size of the cam in proportion to its throw, the quicker it will open or close the valves. Conversely, the smaller the ratio between the size and throw of the cam, the slower it will be in operating the valves.*

41. The problem, in laying out a cam, is to choose a size which will give the valves the proper opening in the desired time. This can best be done by the cut-and-try method. Choose a size of cam as dictated by your judgment, draw its outline according to the method previously given, and inspect the angle q, Fig. 15 (a). If the angle is too large, draw a larger cam with the same throw, and continue this until the angle q suits. The smallest size of cam permissible for a given throw is fixed by practical considerations. These are the size of the shaft and the smallest amount of metal permissible at the thinnest portion of the cam. If these points are kept in mind, no trouble will be experienced in laying out a cam.

42. Laying Out a Round-Pointed Cam.—Full-stroke cams are often found in which the sharp points are rounded over. Such cams are laid out in a slightly different way. Draw the circle $a\ b\ c\ d$, Fig. 16, about o as a center, making its diameter equal to the size of the cam. Draw the vertical center line $d\ e$ and the horizontal center line $a\ c$. Parallel to $d\ e$ draw indefinite straight lines $k\ l$ and $m\ n$ tangent to the circle $a\ b\ c\ d$; lay off $b\ e$ from b upwards, equal to the required throw of the cam. With o as a center and a radius $o\ e$ describe the arc $f\ e\ g$. Choose a radius for the rounded points. Draw an arc $t\ u$ around o with a radius equal to $o\ e$ minus the radius chosen for the rounded points; draw straight lines $k'\ l'$ and $m'\ n'$ parallel to $k\ l$ and $m\ n$, respectively, and at a distance from them equal to the radius chosen for the rounded points. The intersections t and u of those lines with the arc $t\ u$ are the centers of the arcs of the rounded points, which arcs will be tangent to the arc $f\ e\ g$

and the lines *k l* and *m n*. Through the centers *t* and *u* draw an indefinite straight line *i t u q*. This line must be parallel to the line *a c*. If it is not parallel, it shows that one or both of the centers *t* and *u* have been inaccurately

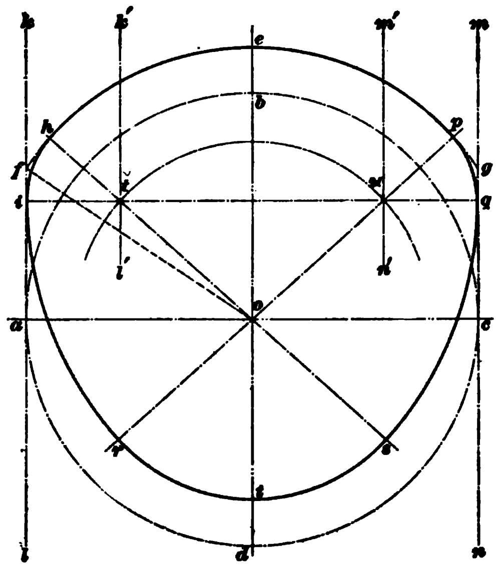


FIG. 16.

located. Having located the centers *t* and *u* accurately, draw the indefinite straight lines *p u o r* and *h t o s* through the centers *t*, *u*, and *o*. Then, with *t* as a center and a radius *t q*, describe the arc *q s*. Also, with *u* as a center and a radius *u i*, describe the arc *i r*. Next, with *o* as a center and a radius *o r*, describe the arc *r t s*. If carefully drawn, the arc *r t s* must exactly meet the arc *q s* at *s*. Furthermore, the distance *d t* must be exactly equal to *b e*.

43. A round-pointed cam will be slightly slower in its action than a sharp-pointed cam of equal throw and size. Referring to the figure, it will be seen that while a sharp-pointed cam will move through the angle *a o f* in order to fully open or close the valve, the round-pointed cam must move through the angle *a o h*. But as the angle *a o h* is

greater than *a o f*, it shows that the round-pointed cam is slightly slower.

Inasmuch as the rapidity of action of the cam depends upon the size, it follows that a sharp-pointed cam can be replaced by a round-pointed cam equally rapid in its action by simply making the new round-pointed cam sufficiently larger in size.

44. The rounding off of the driving corners of a cam promotes better wear. Instead of the cam frame being moved from its mid-position to either extreme position by a sharp corner, as *f* or *g*, sliding along the cam frame, the whole of the arcs *i h* or *p q* comes in contact with the working faces of the frame, thus distributing the wear over a larger surface.

45. Laying Out a Cut-Off Cam.—The throw and point of cut-off being known, the general method of proce-

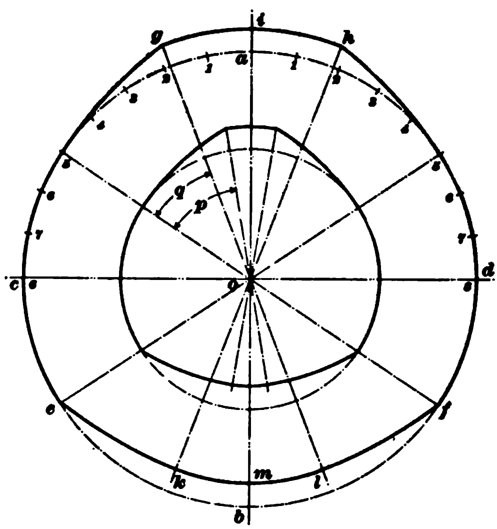


FIG. 17.

dure which allows us to construct a cam for any point of cut-off is shown in Fig. 17. Choose a size of cam and draw a

circle with the size for diameter and the point *o* as a center. Draw the vertical center line *a b* and the horizontal center line *c d*. Then divide the quadrants *a c* and *a d* into a number of equal parts corresponding to the denominator of the fraction representing the part of the stroke at which cut-off is to take place. Thus, if cut-off is to take place at $\frac{5}{8}$ of the stroke, divide both quadrants into eight equal parts. Now, from the point *a*, point off to the right and left a number of parts equal to the numerator of the fraction expressing the point of cut-off. Thus, if the cut-off is to be $\frac{5}{8}$, we point off five divisions to the right and left. Through these points just laid off, and passing through the center *o*, draw the lines *5 e* and *5 f*. From the points of intersection *e* and *f*, with a radius equal to the diameter of the circle *a b*, draw arcs *5 g* and *5 h*. Now on the center line *b a* lay off upwards the distance *a i* equal to the throw. With *o* as a center and a radius *o i*, draw the arc *g i h*. From the intersection points *g* and *h* draw indefinite lines *h k* and *g l* passing through the center *o*. Next, with *g* and *h* as centers and a radius equal to the diameter of the circle *a b*, draw the arcs *e k* and *l f*. Then, with the point *o* as a center and a radius *o k*, draw the arc *k m l*, thus completing the cam. If the cam outline has been correctly drawn, the distance *m b* is exactly equal to the throw.

46. In cams constructed according to this method, the size of the cams influences the rapidity of opening and closing of the valves, in the same manner as explained in connection with the full-stroke cam. In order to clearly bring out this point, a small cam outline has been drawn about the center *o* in Fig. 17. This small cam has exactly the same throw as the large one, and is constructed in the same manner and to cut off at the same point. In order to open the valve, the point *g* of the large cam moves through the angle *q*; the corresponding point on the small cam must move through the angle *p*. But the angle *p* is greater than *q*, hence the valve movement will be slower with the smaller cam and faster with the larger cam.

47. In laying out a cut-off cam to open the valves in a given time, the cut-and-try method described in conjunction with the laying out of a full-stroke cam may be followed with advantage. While it is feasible to find the proper size by calculation, this statement applying to a full-stroke cam as well, it is a process involving considerable knowledge of mathematics.

48. As previously stated, the method here given for constructing a cut-off cam is *general*, in that by it a cam can

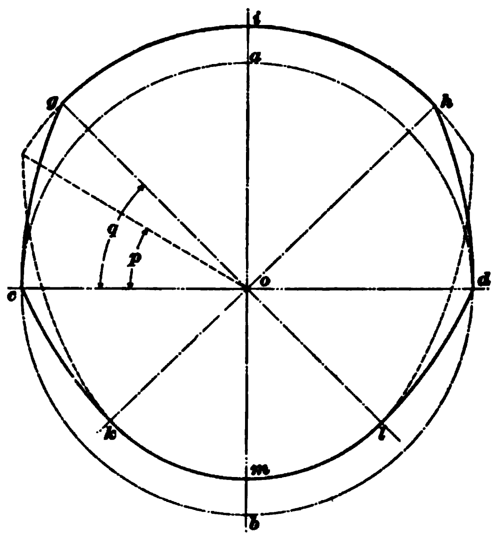


FIG. 18.

be laid out to cut off at any part of the stroke. It is even possible to lay out a full-stroke cam by this method, as is shown in Fig. 18. In this case, both the denominator and the numerator of the fraction expressing the cut-off are 1. Hence, the whole quadrant is laid off to the right and left of *a*, giving the points *c* and *d* as the starting points of the eccentric arcs causing movement of the cam frame. With a radius equal to the diameter of the circle *a b*, and *c* and *d* as centers, the arcs *c g* and *d h* are struck. Then, the throw *a i* having been laid off, with a radius *o i* the arc *g i h*

is drawn with *o* as a center. Now draw the lines *h k* and *g l* passing through the center *o*. Next, with the points *g* and *h* as centers, and a radius equal to the diameter of the circle *a b*, draw the arcs *c k* and *d l*, and then with *o* as a center and a radius *o k*, draw the arc *k m l*, thus completing the outline. If accurately drawn, the distance *b m* is equal to *a i*.

49. Having seen that there is more than one way of constructing a full-stroke cam, it remains to be shown why a different method for laying out a full-stroke cam has been previously given. In order to show clearly why the method first given is preferable, a cam of exactly the same throw and size as the one shown in full lines in Fig. 18 has been constructed about the same center and is shown in dotted lines. A comparison of the angles *p* and *q* shows that for equal size and throw of the cams, the full-stroke cam constructed according to the method given for laying out a cut-off cam is much slower in its action than the cam laid out according to the other method.

50. A cut-off cam designed according to the instructions given will cause cut-off to take place at the point the cam is designed for, *if the cam is set so that the steam valves will be about to open the moment the crank moves past either dead center, i. e., if the steam valves have no lead.* If the cam is set ahead of this position in order to give lead, the cut-off will take place *earlier*. How much earlier it will take place can readily be found by subtracting the fraction representing the part of the stroke at which the steam valves open when lead is given from 1, and then subtracting the remainder from the fraction representing the point of cut-off the cam is designed for. The remainder will give the point of cut-off for the given lead. Thus, if a cut-off cam for half-stroke cut-off be set to open the steam valves at $\frac{19}{20}$ of the stroke, the apparent cut-off will be $\frac{1}{2} - (1 - \frac{19}{20}) = \frac{9}{20}$.

51. When a cut-off cam is to be designed to give a certain apparent cut-off on a given lead, due allowance has

to be made for the lead. This can be done as follows: Subtract the part of the stroke at which the steam valves are to open from 1. Add the remainder to the fraction representing the point of cut-off the cam is to be designed for, and then design a cam for a cut-off equal to the sum of the two fractions. Thus, given the problem of designing a cam to cut off at three-quarter stroke when set so as to open the steam valves at $\frac{15}{16}$ of the stroke, simply design the cam for $(1 - \frac{15}{16}) + \frac{3}{4} = \frac{13}{16}$ cut-off.

SETTING THE VALVES OF LEVER ENGINES.

THE FIXED CUT-OFF GEAR.

52. The first engine we will consider is a fixed cut-off lever engine with one full-stroke cam and one cut-off cam, i. e., of the type shown in Fig. 1. In order to present the most difficult job encountered when setting valves, imagine the valve gear to be all adrift. The advisability of this will be plain when it is considered that a person capable of adjusting the valve gear properly under these circumstances can readily make any necessary adjustments when only some part of the gear is deranged. The steam wipers having been keyed to the forward rocker-shaft at right angles to the forward rocker-arm, slip the exhaust wipers on the shaft and place the latter into its bearings. Key the after rocker-arm to the after rocker-shaft, and place it in position after slipping on the after exhaust crank. Now place the full-stroke cam frame over the shaft and adjust it to suit the size of the cam. Then shift the cam frame in its bearings till its working faces are equidistant from the center of the shaft. Secure the frame in this position in any convenient way. Attach the cam rod and reach rod. Drop the lower hook of the spider over the lower pin of the after rocker-arm. Then, the after rocker-shaft being prevented from turning by any convenient means, raise the reach rod and see if the hook will go freely over the upper rocker-arm pin. If it does, the cam rod is correct in length. If it does not, lengthen or shorten the cam rod until the spider hooks will go freely over each pin

without moving the rocker-arm. Always drop the hook over the lower pin before changing the length of the cam rod; then loosen the rocker-shaft, make your adjustment, secure the shaft again, and then try the hook on the upper pin. When the correct length of the cam rod has been found, we have obtained at the same time the mid-position of the after rocker-arm. It is perfectly feasible to adjust the cam rod by hooking on to either pin before making adjustment for length, but as this course is very liable to be confusing, it is recommended that the spider hook be always hooked over the lower pin when adjusting the length of the cam rod.

Now put on all four levers, with their riders attached. Then, the four valves being fully seated, place both the steam wipers and exhaust wipers in their mid-positions, this being the position in which corresponding points on the wipers are the same distance from the riders they are to engage. Fasten the forward rocker-shaft in this position, and in any convenient way block the exhaust wipers so they can not turn. We have now placed the forward rocker-arm in its exact mid-position, and are ready to key the after exhaust crank to the after rocker-shaft. This shaft being held from turning, and the after rocker-arm standing in the mid-position obtained when finding the length of the cam rod, turn the after exhaust crank about the shaft until its center line is *parallel* to the center line of the forward exhaust crank, as near as can be judged by the eye. Key the after exhaust crank to the after rocker-shaft in the position just found. It is assumed here that the two exhaust cranks have been placed properly in line with each other, so that the exhaust link can be attached to both arms. Now attach the exhaust link, making its length such that it will just go over the pins of the exhaust cranks without tending to move them either way.

The next step is to find the correct length of the full-stroke link. Attach it to the lower after rocker-arm pin. Then, no parts of the gear having been moved from their mid-position, shorten or lengthen the full-stroke link until its hook will drop freely over the forward rocker-arm pin.

Attach the guiding link for the cut-off hook to the full-stroke link; leave everything in its mid-position. Put the cut-off cam frame over the shaft, adjust it to suit the size of the cam, and place it in its mid-position, that is, with its working faces equidistant from the shaft. Attach the cam rod and reach rod, the hook end of the reach rod having been attached to the guiding link at the same time that the link was attached to the full-stroke link. Now adjust the length of the cut-off cam rod until the cut-off hook will drop freely over the forward rocker-arm pin *without moving it from its mid-position.*

Next, put both cams over the shaft and into their respective frames, but do not tighten them yet. Now, place the crank of the engine on either dead center, it does not matter which; then tighten the full-stroke cam to the shaft. With the lower after rocker-arm pin used for the go-ahead motion, as is the common practice, and the cam frame direct-connected to the pin, the full-stroke and cut-off cams will *follow* the crank. That is, if the crank is placed on the after dead center, place the full part of the cams *downwards;* with the crank on the forward dead center, place it *upwards.* Now remove all blocking from the cam frames, rocker-shafts, and wipers, which were placed on them for the purpose of preventing any motion while adjusting the gear; drop the cut-off hook over the forward rocker-arm pin. Next, rotate the cut-off cam towards the crank until it is hard against the cam frame. If secured in this position, the steam valves when controlled by the cut-off cam will not have any lead. If lead is desired, continue to move the cut-off cam and cam frame in the proper direction until the proper steam valve has the required lead. The cam should then be secured to the shaft. The valve gear is now properly adjusted.

If all adjustments are made in the manner described, there is no necessity of placing the crank on the other dead center to see if the lead is the same, etc. Doing so, however, and trying the hooks over the various pins will be a check on the correctness of the adjustments made. If

some parts should fail to be in their mid-position for this crank position, the full-stroke gear being tested *first*, it simply shows that some adjustment has been improperly made. It will then be necessary to run all over the adjustments once more to find just where the fault lies.

53. In this style of gear the angularity of the connecting-rod will not allow an equal cut-off on both strokes. If an attempt be made to equalize the cut-off, as can be done by lengthening or shortening the cut-off cam rod, the steam valves will not open at the correct time any more. As this unequal cut-off is only a matter of very slight importance, it is recommended that no attempt be made to equalize it.

SETTING THE VALVES OF THE SWEENEY ENGINE.

54. In order to present the worst case of valve setting with the gear shown in Figs. 3 and 4, we will here again assume that the gear is all adrift. Key the forward rocker-arm to the forward rocker-shaft at right angles to the steam wipers; slip the exhaust wipers on the shaft and put it into its bearings. Key the after rocker-arm to the after rocker-shaft; slip on the after exhaust crank and put the shaft into the bearings; put on the four levers and riders. Then, all four valves being closed, rotate the forward rocker-shaft until corresponding points on the two steam wipers are equidistant from their respective riders. Secure the shaft in this position.

Next, place the exhaust wipers into their mid-position and secure them there. Rotate the after rocker-arm until it is parallel to the forward rocker-arm, and secure the shaft. Turn the after exhaust crank until its center line is *parallel* to the center line of the forward exhaust crank. Key the after exhaust crank to the after rocker-shaft in this position. Put on the exhaust link connecting the two exhaust cranks, making sure that its length is such that it will not move the exhaust wipers from their mid-position.

Now put the three cam frames over the shaft; adjust each one to suit the size of its cam and place them with their

respective working faces equidistant from the shaft. Secure the cam frames in their mid-positions in any convenient manner.

Couple on the three cam rods, and attach both full-stroke cam rods to the after guiding link, which has previously been placed over the pin v of the vibrating arm V.

Attach the cut-off cam rod to its pin on the arm V'. Now, with the go-ahead hook dropped over the pin v, adjust the length of the go-ahead full-stroke cam rod so that the vibrating arm V will stand perpendicular to the slides, as near as can be judged by the eye. No very great accuracy is required for this operation. Next, adjust the length of the backing cam rod so that its hook can be hooked over the pin v *without moving the vibrating arm from the position occupied when the go-ahead hook is over the pin.* The valve gear is usually set so that the upper hook in the after link is the go-ahead hook. This should be remembered when the cams are placed on the shaft.

Next, adjust the length of the cut-off cam rod so that the arm V' is in the same position as the arm V, as near as can be judged by the eye. A little variation either way does not make any particular difference or affect the operation of the valves.

Now put the forward guiding link over the forward rocker-arm pin, the cut-off reach rod being attached to its upper end and the full-stroke reach rod to its lower end. Then attach the cut-off reach rod to the upper pin of the arm V'. Adjust the length of the cut-off reach rod until its hook will drop freely over the forward rocker-arm pin *without moving the steam wipers.* Attach the full-stroke reach rod r to its pin on the arm V, and adjust its length so that it will also hook freely over the forward rocker-arm pin. Next, attach the exhaust reach rod r' to the after rocker-arm pin and to the same pin of the arm V the full-stroke reach rod is attached to. Make its length equal to the distance from the center of the after rocker-arm pin to the center of the pin in V. Now remove all blocking preventing motion of the rocker-shafts, exhaust wipers, and cam frames during adjustment.

Place the crank on either dead center. Next, put the three cams in their respective frames, remembering that the cams *follow* the crank. The go-ahead full-stroke cam rod being hooked over the pin *v*, advance the go-ahead cam in the direction of rotation of the crank when going ahead. Advancing the cam forces the cam frame with it, and hence opens a steam valve. Continue to advance the cam until the valve has the required lead. It will be understood that the first part of the movement of the cam from its mid-position simply takes up the drop of the steam wipers, and that it must advance quite a little from its mid-position before the steam wiper will come in contact with the corresponding rider. Secure the go-ahead cam to the shaft. Now hook the backing full-stroke cam rod over the pin *v*, and advance the backing cam towards the crank until the lead is equal to that in the go-ahead motion. Secure the backing cam.

Drop the go-ahead full-stroke cam rod again over the pin *v* and the cut-off reach-rod hook over the forward rocker-arm pin. Advance the cut-off cam towards the crank until the proper lead has been given. Secure the cam to the shaft, and the valve setting is completed.

55. It is not possible to change the time of opening of the exhaust valves in reference to that of the steam valves when in full-stroke gear by any change in adjustment. The period elapsing between the opening of one exhaust valve and that of the opposite steam valve depends entirely upon the drop of the steam wipers. The more lead given in full-stroke gear, the earlier the opening of both sets of valves, and *vice versa*. In the cut-off gear, by giving less lead than is given for full stroke, the time elapsing between the opening of opposite valves will be lengthened; if more lead is given, it will be shortened.

SETTING THE CALIFORNIA CUT-OFF.

56. To set the valves of an engine with a California cut-off, first adjust the full-stroke gear in the same manner as was explained in connection with the fixed cut-off engine;

that is, adjust all the parts of the full-stroke gear so that they are in mid-position, the cam rod and links of the proper length, and the cam fastened in its proper position.

Now connect up the cut-off gear. Then rotate the crank from the dead-center position so far occupied until the cross-head is exactly at half stroke. Adjust the rod *F*, Fig. 7, until the crank *G* stands vertical. Unhook the spider hook from the after rocker-arm pin and place it midway between the pins, so that the wipers can be returned to their mid-position and all four valves closed. This done, place the double crank *I* in its mid-position, that is, in line with the crank *G*. Now, without moving the double crank, adjust the length of the rods *m* and *m'* so that both cut-off slides *s* and *s'* will be in their mid-position, that is, the upper corner of their inclined surfaces should be directly in the same vertical plane as the center of the rollers, the cut-off hand lever occupying the position indicating least cut-off. The valves are now set.

57. With the California cut-off, the valves will cut off at the same point of the stroke on the forward and return strokes. The reason for this is not far to seek: the cut-off mechanism being operated from the cross-head, the disturbing influence of the connecting-rod is eliminated; hence cut-off, instead of depending upon the position of the crank, depends upon the position of the cross-head.

Since but one cam is used, lead can not be given to the steam valves or exhaust valves by advancing the cam. If exhaust lead is necessary, the only thing left is to rider the exhaust levers. The blowing through of live steam into the exhaust pipe at the beginning of the stroke must then be put up with.

SETTING THE REES CUT-OFF.

58. Referring back to Figs. 8 and 9, imagine that the valve gear is all adrift. Place the cam frame with its working faces equidistant from the center of the shaft and secure it there. Assemble the clutch, loose arm, and pawls, and then key the clutch to the forward rocker-shaft so that the

loose arm is at right angles to the steam wipers when both pawls are in the clutch. Slip on the exhaust wipers and place the shaft in its bearings. Slip the after exhaust crank and crank arm *i* on the after rocker-shaft and place it into its bearings. Now, by trial, find the correct length of the cam rod and the correct position of the after rocker-arm, in the same manner as was explained in connection with the fixed cut-off engine. Secure the after rocker-shaft. Now place the steam wipers and exhaust wipers into their mid-position and secure them there. Rotate crank *i* on the after rocker-shaft until it is parallel to crank *h*, and key it on in this position. Put on the link *n*, making its length such that it will not move the two cranks *i* and *h* from their mid-positions when placed over its respective pins. Rotate the after exhaust crank on the after rocker-shaft until its center line is parallel to that of the forward exhaust crank, and then key it on in this position. Place the exhaust link over the pins of the exhaust cranks, making its length such that it will not move either exhaust crank when placed on its respective pins. Put the crank on either dead center and put the cam on the shaft, remembering that with the lower after rocker-arm pin as the go-ahead pin, the cam will follow the crank. Care must be taken not to move the cam frame from its mid-position when putting the cam on. After the cam is fastened to the shaft, remove all temporary fastening devices from the cam frame, wipers, and rocker-shafts. Drop the spider hook over the go-ahead rocker-arm pin. Connect up the cut-off gear.

Now turn the crank slowly in the go-ahead motion until the cut-off block has withdrawn the pawl from the clutch. Measure at what point of the stroke cut-off took place. Then turn the crank ahead again until cut-off has occurred on the other side of the cylinder. Measure the cut-off. If the two measurements are alike, the cut-off gear is set correctly. If they do not agree, lengthen or shorten the rod *F* until the cut-off is equal, taking a new set of measurements after each adjustment of *F*. As only one cam is employed, lead can not be given to either steam or exhaust valves by advancing the cam.

SETTING THE VALVES OF THE SWAIN ENGINE.

59. The valve gear being assembled, proceed as follows: Drop the link so that the go-ahead cam rod controls the main valve. Place the crank on one of the dead centers. Shift the go-ahead cam until it is a little more than a right angle **ahead** of the crank in the forward motion. Fasten the cam temporarily. Now adjust the length of the cam rod until the main valve has the required lead. The outboard bonnet should be removed from the main-valve chest, so that the valve and ports can be seen. Now turn the crank to the other dead center and see if the lead is the same. If not, lengthen or shorten the cam rod until the lead is equal on the forward and return stroke. When the lead has been equalized, place the crank on either dead center again, loosen the go-ahead cam, and turn it about one-eighth of a turn around the shaft in a direction opposite to that in which the crank moves when going ahead. Then turn it back again until the valve has the lead determined upon. Turning the cam backwards first and then ahead again insures that all slack in the connections is taken up in the proper direction. Fasten the cam permanently. Now throw the link up so as to bring the main valve under the control of the backing cam. Set the valve and find the true cam position in exactly the same manner, making the lead equal to that given in the go-ahead motion. Throw the link down again and turn the crank in the go-ahead motion until the main valve just opens the proper steam port. Now adjust the length of the crab-claw carrying rod until the cut-off valve just opens. To set the cut-off mechanism (see Fig. 10), move the block in the rocker-arm q, to which the reach rod r is attached, to the farthest limit of its travel. Turn the crank until the cross-head is at half stroke. Then adjust the length of the reach rod r until the rocker-arm q *will occupy the same position* when its block is at either extremity of its travel. As the end of the rod r describes an arc of a circle in moving the block from one extreme position to the other, the rocker-arm will not remain stationary while the block is being shifted, owing to the fact that the block

is shifted in a straight line instead of in an arc having a radius equal to the length of the reach rod. The correct length of the reach rod having been found, slide the block to its extreme outer position, i. e., for the latest cut-off. Turn the crank slowly ahead until cut-off takes place. Measure the point of the stroke at which cut-off occurred. Turn the crank ahead again until cut-off occurs on the next stroke. If the cut-off is equal on both strokes, the cut-off mechanism is correctly set. If not, shift one or both of the studs which engage the nose of the crab claw until the cut-off has been equalized. The valve setting is now completed.

60. General Remarks.—The directions previously given will enable the student to set the valves of any river engine if some judgment be employed. Before making any change at all in the adjustment of the valve gear, study out what the effect of the change will be on all the different parts connected to the piece the adjustment of which is changed. Then, and not until then, go ahead and make the change, noting if the actual effects are those you anticipated. If not, find the flaw in your reasoning. Remember, it is impossible to lay down a set of hard and fast rules, inasmuch as conditions will vary with each case, and hence the student must learn to reason for himself from the hints and methods of procedure given in this chapter on Valve Setting.

VALVES AND AUXILIARY MACHINERY.

THE FRISBIE BALANCED VALVES.

61. The Frisbie engine for river steamers uses a method of balancing a single-seated valve which is extremely simple and effective. The construction of the steam valve and exhaust valve differs somewhat; both are shown in Fig. 19, which is an athwartship section of the cylinder, looking forwards. The steam valve *a* is a hollow casting of the cross-section shown; the seat is at the lower end. The upper end is turned truly cylindrical to fit a cylinder *e*

projecting from the steam-chest cover. Packing rings *b*, *b* insure a tight joint. The lower part of the valve is a little larger than the upper part; owing to the fact that this upper part fits steam tight in the cylinder, the steam in the steam chest *c* can act only upon the flange. The valve stem passes

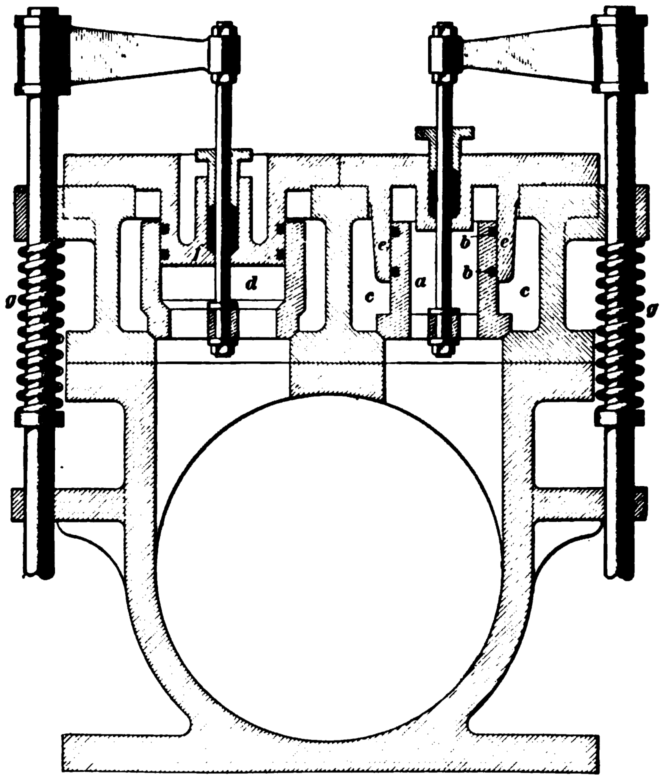


FIG. 19.

through a boss central with the outside of the valve and is fastened to it by a nut.

The exhaust valve *d* is slightly different in construction. It is bored out to fit closely a cylindrical projection *f* extending downwards from the exhaust-chest cover. This projection, or piston, is provided with packing rings and is made slightly smaller in diameter than the seat of the valve. Thus the

force acting upon the under side of the valve and tending to open it when live steam is in the cylinder is greatly reduced, the steam acting only upon a ring having an area equal to the difference of areas between those of the seat and piston. The valve is attached to the stem in the same manner as the steam valve.

62. In this design of valve, the good qualities of the single-seated poppet valve are retained. With the ordinary double-seated poppet valve, the difference in expansion between the seats in the chest and the valve proper makes it quite difficult to get and keep the valve tight, even when ground in while the valve and seats are hot. The ordinary single-seated poppet valve is easy to grind in and keep tight, and this valuable quality is possessed by the Frisbie valve, it being simply a balanced single-seated valve.

63. In the Frisbie engine, of which some are to be found on the Mississippi, the valves are lifted directly by the wipers without the intervention of any levers. Referring to Fig. 19 it will be seen that each valve is attached to its own lifter rod. Spiral springs *g*, *g* insure a prompt closing of the valves. There are four separate wipers, one for each valve; but instead of being on top of the valve chests and side pipes, they are placed near the bottom and at the sides of the cylinder, the two exhaust wipers on one side and the two steam wipers on the other side. They are actuated by one full-stroke cam, serving for both motions when following full stroke. A cut-off cam is provided to operate the steam valves in the go-ahead motion when required. As this valve gear is very simple in comparison with that of the lever engine, it will not be further described here.

THE STEERING GEAR.

64. Steam steering gears being in common use on river steamers, a description of a gear frequently used is here given. Fig. 20 shows a plan view, side elevation, and rear view of the **Cincinnati steam steering gear,** as made

by Crawley & Johnston. This gear is noted for its light weight, simplicity, and efficiency, the three things of paramount importance in the river service. Referring to the figure, a, a_1, a_2, and a_3 are the tillers, there being four rudders. These tillers are connected together by the tiller

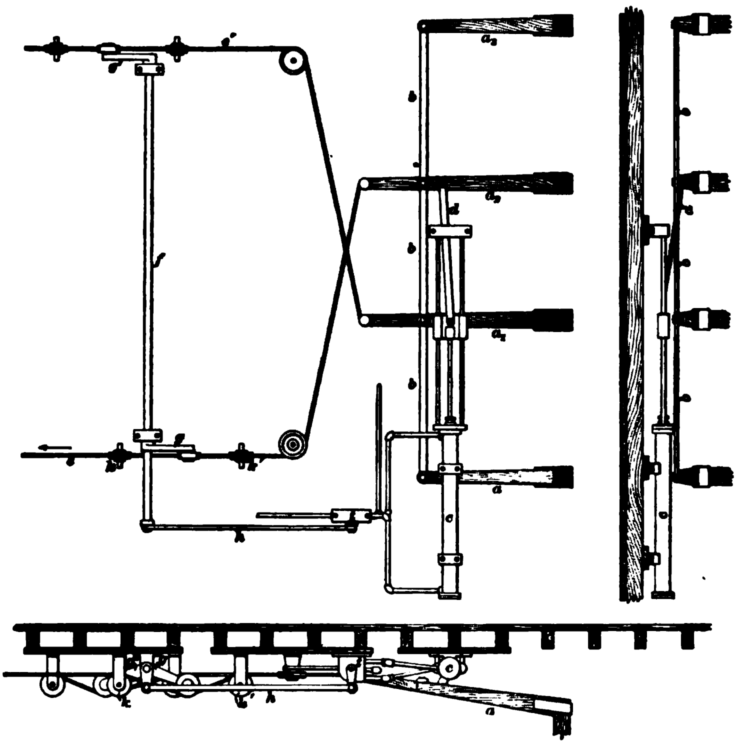


FIG. 20.

coupling rods b, b, which cause the four rudders to move simultaneously. A steam cylinder c is fitted with a piston, piston rod, and cross-head, the cross-head being connected to one of the tillers by the connecting-rod d. This cylinder in stern-wheel steamers is bolted to the under side of the deck and just above the tillers. A pipe leads from each end of the cylinder to a valve chest t containing a rotary valve, by means of which steam can be admitted to

or exhausted from each side of the piston. The tiller ropes *e*, *e'* are led over sheaves to the steering wheel in the pilot house and pass over the drum of the wheel. A rock-shaft *f* is placed parallel to the cylinder in the position shown. This rock-shaft carries levers *g* and *g'* keyed to each end in the relative positions shown in the side elevation. The free end of each lever carries a small roller, which rests on the tiller rope. Any motion of the rock-shaft is transmitted to the rotary valve in the valve chest by cranks keyed to the rock-shaft and valve stem, respectively, these cranks being connected by the valve rod *h*. Let the pilot move the wheel so that the tiller rope *e* will move in the direction of the arrow. Then the first movement of the wheel takes up the slack in the tiller rope *e* and increases the slack of the rope *e'*. Taking up the slack between the two guide sheaves *k* and *k'* causes the free end of the lever *g* to move up, the lever *g'* dropping down an equal amount. This movement forces the valve rod *h* aft, rotates the valve in the steam chest, opens the steam passage leading to the starboard end of the cylinder, and also opens the exhaust port of the port end of the cylinder. Steam being admitted to the starboard side of the piston, the piston, and hence the tillers, move to port. Now, as long as the pilot continues to move the steering wheel, the slack in the tiller rope *e* is taken up, the valve admits steam to the starboard side of the piston, and the tillers continue to move to port. But as soon as the pilot stops turning the wheel, the continued motion of the piston and tillers slacks up the rope *e* and tightens the rope *e'*, thus causing the rock-shaft to rotate in the opposite direction. This shuts off the steam supply from the starboard end of the cylinder and opens the exhaust port, the valve at the same time admitting steam to the port side of the piston and cushioning it. The cushioning throws the tillers slightly to starboard, thus releasing the strain on the rope *e'*. As a consequence of this, the valve returns to its mid-position and the tillers remain at rest in their position as long as the wheel remains stationary. When the pilot revolves the wheel so as to tighten rope *e'*, the tillers move to starboard.

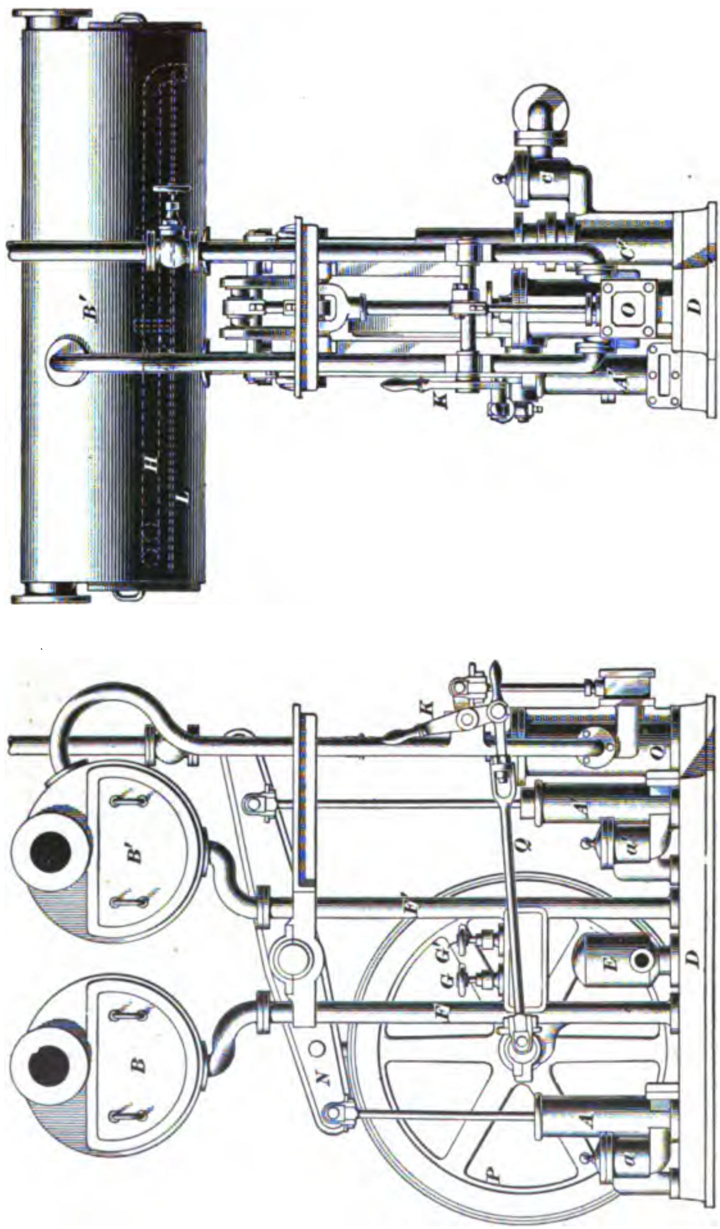


FIG. 21.

65. To set the valve properly is a simple matter. Rotate the rock-shaft so that the levers are in their mid-position; then lengthen or shorten the valve rod until the valve is in its mid-position. The valve setting is now completed.

THE FEED APPARATUS.

THE DOCTOR.

66. The feed-pumps and heaters of a Western river steamer are shown in Fig. 21. This pump is known as a **doctor,** and is in common use. The doctor consists essentially of a beam engine, with crank and fly-wheel, operating four pumps, two on each side. The *lifting* pumps *A* and *A'* are single-acting; they draw the water from the river and discharge it into the open heaters *B* and *B'*. Here the water is heated by being brought in direct contact with the exhaust steam, the exhaust from each engine passing through its own heater. The *force* pumps on the other side take the water from the heaters and force it into the boilers. One of these pumps is shown at *C'*. The base plate *D*, upon which the doctor is erected, contains the various passageways forming the water connections between the pumps, the passages being cored in the casting. The suction pipe to the river connects directly with the vacuum chamber *E*, so called since a partial vacuum is necessarily maintained therein. It should be remembered that the doctor is located on deck, and hence above the water level. The object of this vacuum chamber is to prevent shocks and to steady the flow of water in the suction pipe. The lifting pumps being single-acting, the column of water ascending the suction pipe would, if no such chamber were provided, be suddenly brought to rest by the closing of the suction valve of the pump. The kinetic energy of the moving body of water would be given up suddenly and be expended in a violent blow or shock; but with a vacuum chamber the column of water, with the exception of that comparatively

small portion of it between the piston and the chamber, is not suddenly checked, but continues to move during the down stroke of the pump plunger, compressing the rarefied air in the vacuum chamber. Shocks are thus obviated and the inflow of water steadied. A cored passage in the base connects the vacuum chamber with the suction end of the two lifting pumps. The water is delivered through the delivery casings *a* and *a'*, which contain the delivery valves, into passages in the base plate which connect with the hollow columns *F* and *F'*, the column *F* communicating with *a* and the column *F'* with *a'*. The water does not pass straight up the columns, however, but is led through the valves *G* and *G'*, and then back into the columns, and thence to the heaters. When the doctor is stopped for the purpose of opening and examining the valves of the lifting pumps, these valves are closed and serve to retain the water in the heaters. The heaters consist of wrought-iron shells with cast-iron heads; the exhaust from each engine enters its own heater through one head and leaves it through the other head. The exhaust comes in contact with a coil *H* of copper pipe near the bottom of each heater; the lifting pumps force the water through this coil and discharge it at the bottom of the heater below the diaphragm *L*. While this diaphragm does not in any way prevent the exhaust steam from coming in contact with the water, it acts as a baffle plate, preventing violent agitation of the surface of the water in the heater, and at the same time forms a quiet spot for the collection of floating impurities. An overflow pipe is attached to the heater on about the level of this diaphragm, which not only prevents the flooding of the heater, but also serves to carry off the oil and other light impurities floating on the surface of the water. The heated water flows by gravity down hollow columns opposite *F* and *F'* to the suction side of the force pumps, which are single-acting plunger pumps. It now passes through the delivery chambers, one of which is shown at *c*, into two pipes which unite to form the main feed-pipe. The exhaust pipes from each heater are usually united to form one main exhaust

pipe, extending from near the heaters to near the back end of the boilers. Here this pipe branches off again into two branches, each branch leading to one of the smokestacks. Provision is usually made for turning the exhaust either into the smokestack for the purpose of increasing the draft or directly into the atmosphere, by splitting the pipe into two branches and placing a rotary valve at the junction. The main feed-pipe passes through a stuffing-box into the after end of the **Y** fitting at the after junction of the two exhaust pipes; it then passes through the whole length of the main exhaust pipe and emerges through a stuffing-box at the forward end, where the exhaust is split again. The main feed-pipe then leads downwards and branches off to each boiler. By passing the feed-water through the heaters and exhaust pipe, it is heated to a high temperature.

The pumps are all attached to the walking beam *N* connected to a steam cylinder *O* at one end and to a crank and fly-wheel *P* at the other end. The slide valve of the engine is operated by a small crank, or occasionally an eccentric, on the end of the fly-wheel shaft. To allow the cylinder to be readily warmed up when starting, and also to facilitate the starting of the doctor, the eccentric-rod *Q* is hooked over a pin of the bell-crank *K*. When the rod is unhooked from this pin the slide valve can be operated by hand.

67. While the doctor may look very complex at first sight, it is really a very simple machine, in which the working parts are simple in construction and very accessible. In river service, where the water is frequently very muddy and must always be pumped against very high pressures, the doctor has proven economical and efficient, and has held its own against direct-acting steam pumps and injectors. The general demand for lightness and simplicity of the machinery is well met in the manner in which the frame is made use of in providing the water passages, and in the design illustrated by making the steam pipe and exhaust pipe of the steam cylinder serve as cross-head guides.

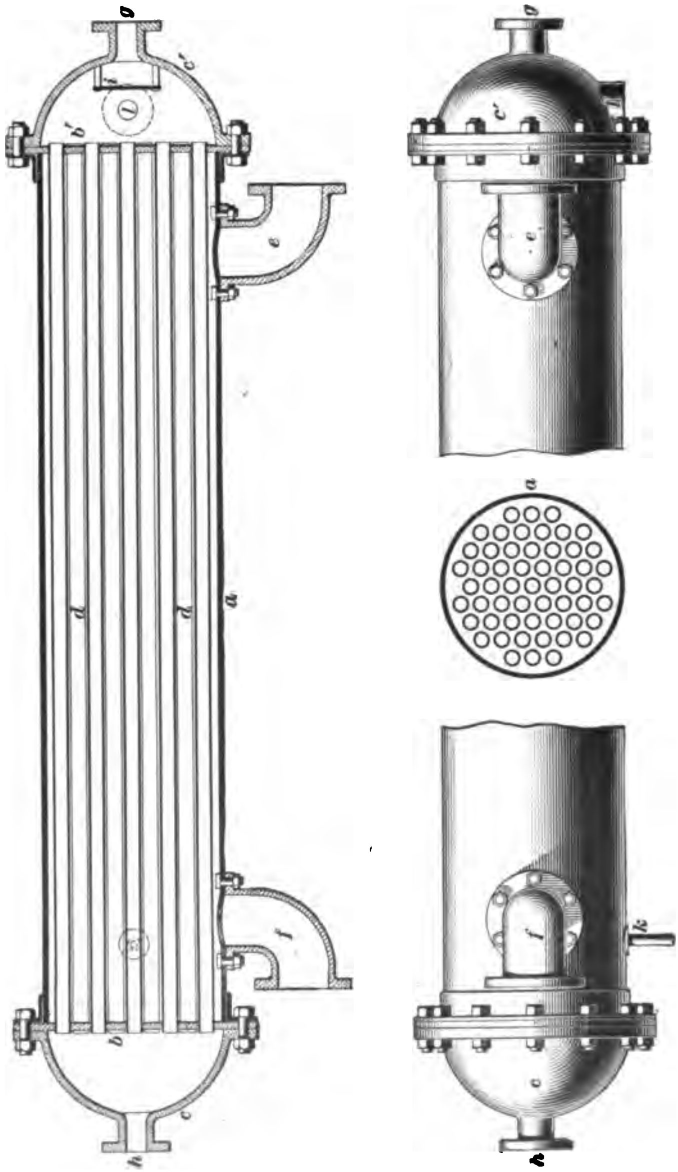


FIG. 22.

THE CLOSED FEED-WATER HEATER.

68. The heaters shown in connection with the doctor are known as **open heaters** from the fact that the part of the heater which contains the feed-water is open to the atmosphere through the exhaust pipe. A great many steamboats, however, use **closed heaters.** In these the feed-water passes through a closed system of pipes under pressure, and is not exposed to the atmosphere at all during its passage from the suction pipe of the pump to the boilers. Such a heater is shown in Fig. 22.

The heater consists of a cylindrical wrought-iron or steel shell *a*, to the ends of which angle-iron rings are riveted. The tube sheets *b*, *b'* and cast-iron heads *c*, *c'* are bolted to these rings. Tubes *d*, *d* are expanded into the tube sheets so as to form steam-tight and water-tight joints. The exhaust steam from the engine enters the nozzle *e* and leaves the heater through the nozzle *f*. It surrounds the tubes and heats the feed-water which enters through *g* and leaves at *h*. The plate *i* serves to distribute the entering feed-water. Any condensed exhaust steam is carried off through the pipe *k* attached to the bottom of the heater; the water side of the heater can be emptied through a pipe attached at *l*. This style of heater is not adapted to a doctor of the description given, a pump which will simply force the water through the heater being all that is required. This pump handles cold water only, inasmuch as the water is heated after it leaves the delivery side of the pump.

The rules of the Board of Supervising Inspectors provide that the feed-water for a boiler used in connection with a non-condensing engine shall not be admitted at a lower temperature than 180° F. Hence the necessity of employing a heater on river steamers will be apparent.

Open heaters of the kind used in connection with the doctor are objected to by some engineers on the ground that the oil used in the cylinders is carried into the heaters by the exhaust steam, and that consequently at least some of it mixes with the feed-water and is carried into the boilers, where it deposits on the plates. It can not be denied that this is true

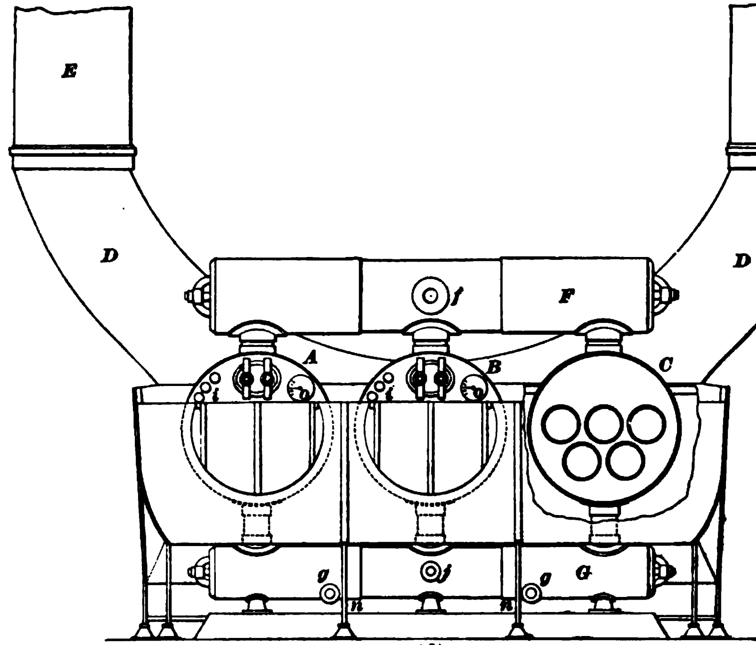
to some extent, but since the river water is usually very muddy, the boilers must be frequently cleaned on account of the mud deposited; the oil carried in is then removed with the mud.

In the closed feed-water heater, the exhaust steam does not come into contact with the feed-water, hence no oil can mix with it.

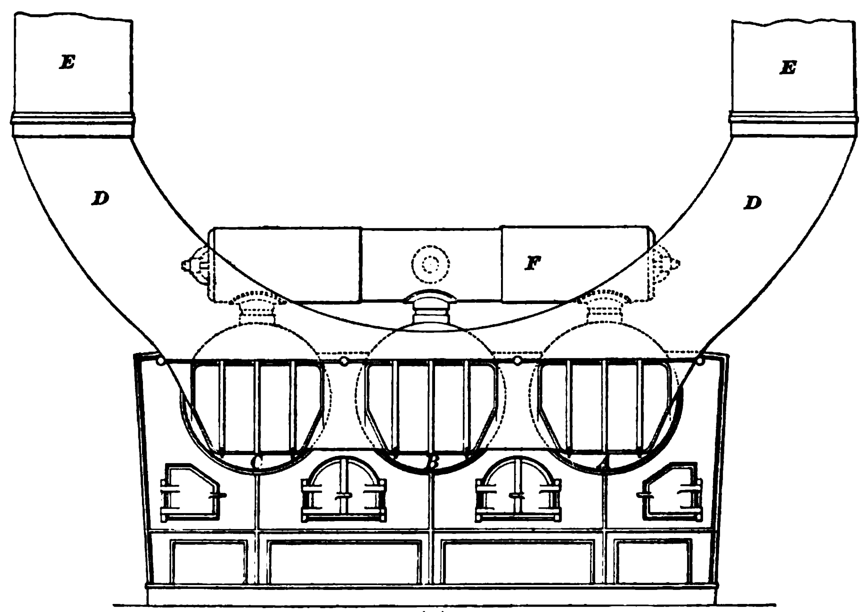
THE BOILERS.

THE FLUE BOILER.

69. A typical Western river steamboat boiler plant is shown in Fig. 23. Fig. 23 (*a*) is a front elevation, looking aft. Fig. 23 (*b*) is a side elevation, looking from port to starboard. Fig. 23 (*c*) is a plan view, a section being taken through the port boiler along its horizontal center line in order to show the flues and the inside of the setting. Fig. 23 (*d*) is a rear view of the boilers and setting, part of the setting being broken away around the starboard boiler, through which a vertical section has been taken in order to show the location of the flues. As clearly shown in the illustration, there are three boilers, marked *A*, *B*, and *C*, respectively. These boilers are of the flue type, containing a number of flues—five in this instance. The location of the flues is clearly shown in Fig. 23 (*c*) and (*d*). There is one wide grate common to all boilers; when there are more than three boilers in a battery, there may be two or more separate furnaces. The breeching or front connection *D D* is common to all boilers, and is provided with doors, as shown, to allow the flues, etc., to be examined and cleaned. The boilers are externally fired and the gases of combustion surround about two-thirds of the shell. They pass to the rear of the boiler, and then through the flues forwards again into the breeching, whence they pass up the two stacks *E*, *E*. The use of two stacks is common on all Western river steamers, as it gives the pilot an unobstructed view forward and aft.

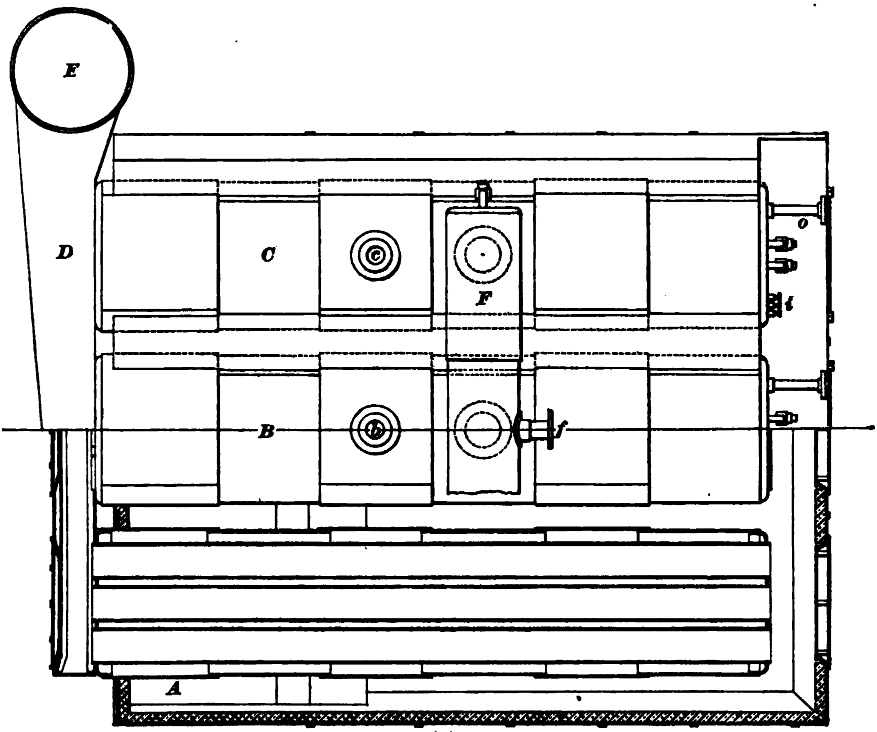


(d)

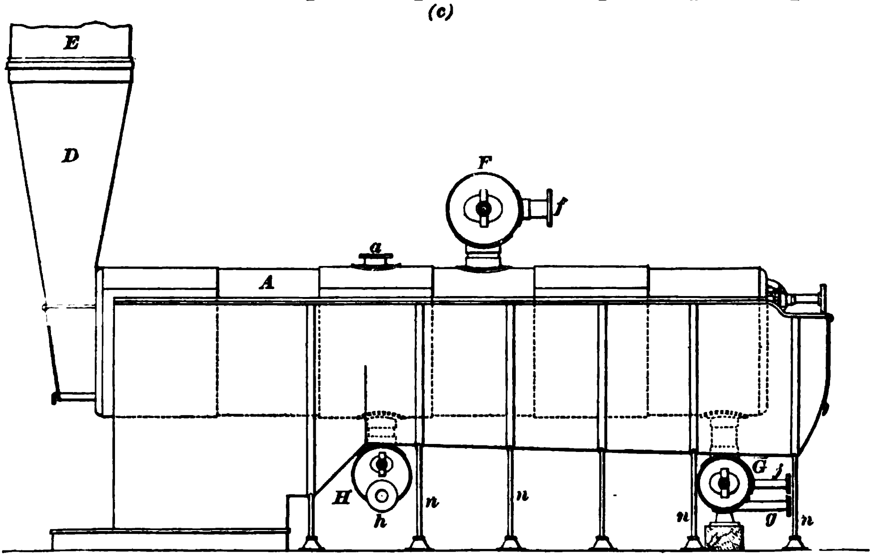


(a)

F



(c)



(b)

23.

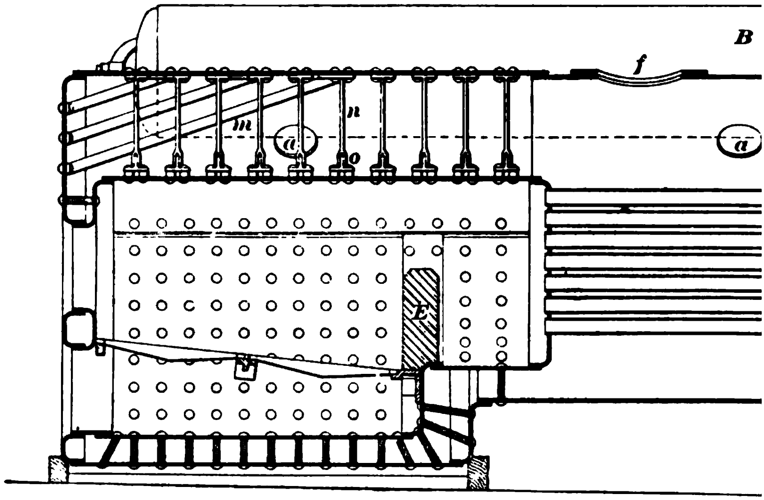
When only one stack is used, as is sometimes done in the smaller vessels, it is usually set on one side of the boat, so as not to obstruct the view of the pilot. Each boiler is provided with its own safety valve; the nozzles to which the valves are attached are shown in the illustration at *a*, *b*, and *c*. Occasionally two safety valves are used, one of them being a lock-up safety valve, set by the boiler inspector to the steam pressure allowed, and the other a common safety valve. The three boilers are connected by suitable flanged nozzles to the steam drum *F*, forming a steam reservoir. The main steam pipe leading to the engines is connected to the nozzle *f*. All other steam pipes, such as those for the whistle, steering gear, feed apparatus, capstan, etc., are also connected to the steam drum at suitable places. The bottoms of the three boilers are connected together by two mud drums, or **stand pipes,** as they are often called. The rear mud drum is shown at *G* and the forward mud drum at *H*. These mud drums are supposed to provide a quiet place for the collection of mud and sediment held in mechanical suspension in the feed-water. Each drum is provided with two nozzles to which the **mud valves** or blow-off valves are attached. Suitable pipes lead the water overboard. The nozzles *g*, *g* of the rear mud drum are attached to the lower part of the drum and point aft. The nozzles on the forward drum are attached to the lower part of the two heads. One of these nozzles is shown at *h*. The nozzle *j* in the center of the rear mud drum is for the donkey feed-pipe. Each boiler has its own main feed-pipe and check-valve; the water is introduced through the rear head, and passing through a coil of pipe is delivered in the steam space near the front of the boilers. The gauge cocks, as shown at *i*, are in the rear head of the boiler, as are also the float water gauges *o*. These water gauges will be explained later on. The purpose of placing the gauges in the rear head of the boilers is to allow the engineer to see the height of water in the boilers without leaving the engine room.

Suitable manholes and handholes are provided to allow examination and repair of the boilers, mud drums, and

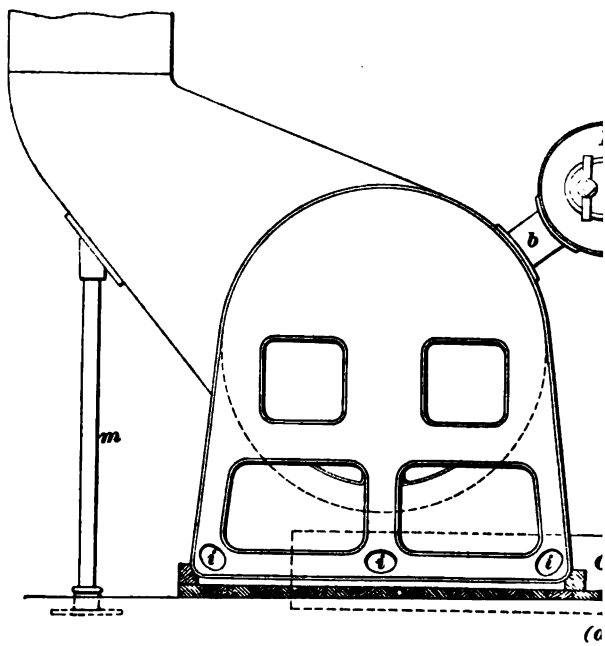
steam drums. The front of the boiler setting is of cast iron; the sides, rear, bottom, and top of sheet iron. Every part of the setting that is exposed to the fire is lined with fire-brick. The boilers and setting are secured to the deck by the tie-rods *n*, *n*.

THE FIRE-BOX BOILER.

70. A pair of fire-box boilers are shown in Fig. 24, view (*a*) being a front view looking forwards, and view (*b*) a vertical fore-and-aft section through the starboard boiler. Each boiler is composed of two different parts, the forward part being cylindrical and the after part approximately rectangular with a semicircular top. There are two separate furnaces in each boiler, each furnace having its own nest of tubes leading to the front connection *A*, which is common to both furnaces. The steam generated in the boilers passes through the nozzles *a* and *b* into the steam drum *B*. The main steam pipe is connected at *c* to the steam drum. The auxiliary steam pipes are also connected to this drum. The water space of both boilers is connected by the mud drum *C*. In this design each boiler has its own front connection and smokestack, although more than one boiler may be connected to one stack. Each boiler has its own safety valve, which is attached at *d*. A manhole is shown at *f* and some handholes at *i*. These are placed in various parts of the boiler to allow it to be examined and cleaned. Suitable manholes and handholes are also provided for the steam drum and mud drum. As clearly shown in the figure, the furnaces are surrounded entirely by water, hence this boiler belongs to the wet-bottom type. The flat surfaces of the boiler are stayed by the screw stays *l* and the diagonal braces *m*. The crown sheets of the furnaces are stayed by the crown bars *o* made of **T** iron, which are riveted to the crown sheets by numerous rivets. Distance pieces or thimbles are placed between the top of the crown sheet and the bottom of the crown bars. The crown bars are connected to the top of the boiler by the toggle braces *n*, which are

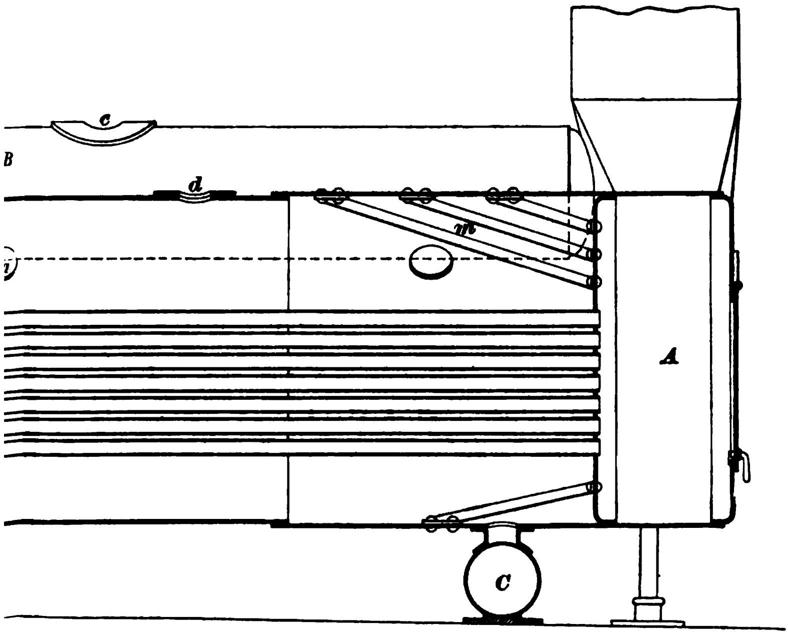


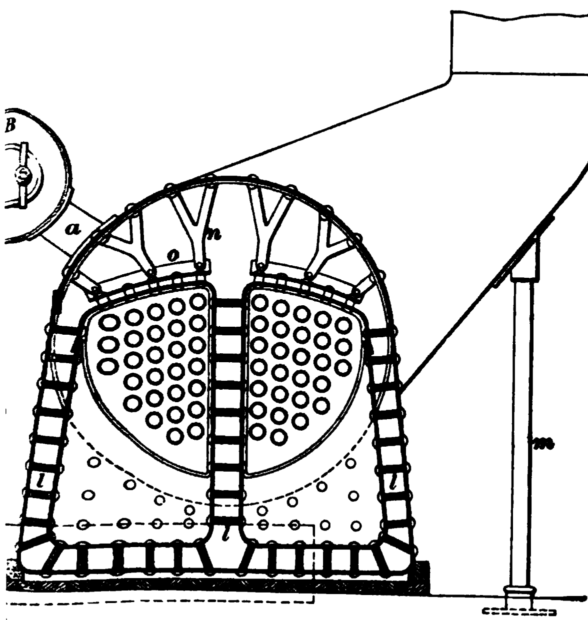
(b)



(a

FIG





24.

cottered to the crown bars and riveted to the shell. In the particular design of boiler here shown, a bridge wall *E* is built in each furnace. However, fire-box boilers are frequently built without a bridge wall. The smokestacks are supported by the stanchions *m*, *m*. The boilers are secured to the deck by tie-rods, not shown in the illustration. This style of boiler being internally fired, there is no elaborate setting required for them.

THE LOCOMOTIVE BOILER.

71. A locomotive marine boiler, so called from its resemblance to the boiler of the ordinary locomotive, is shown in Fig. 25. Like the fire-box boiler just described, which it resembles externally, it consists of two differently shaped parts riveted together. The forward part is cylindrical, the cross-section of the after part is rectangular with a semicircular top. It has one large furnace, which is surrounded by water on the sides and top, but open at the bottom, thus making it a dry-bottom boiler. It is provided with a steam drum *A*, the heads of which in the larger sizes are stayed by through stayrods *a*, *a* provided with nuts on the inside and outside of the heads. The ash pit is entirely separate from the boiler proper, the grate being placed at the bottom of the furnace. The flat surfaces of the furnace and also the crown sheet are stayed by screw stays screwed into the sheets and riveted over. That part of the rear head which is not stayed to the furnace plate is stayed by diagonal stays *b*, *b*, similar stays being employed for the front head. The bottom of the water legs, as the spaces surrounding the furnace are often called, is closed by a cast-iron or wrought-iron mud ring *c*. The water legs are provided with handholes in suitable locations; one of these handholes is shown at *e*. At *f* a manhole is shown. The safety valve is attached at *g*. The gases of combustion traverse a nest of tubes extending from the rear tube sheet to the front head, and are discharged into the front connection *h*, whence they pass up the stack. The main steam pipe is connected to the

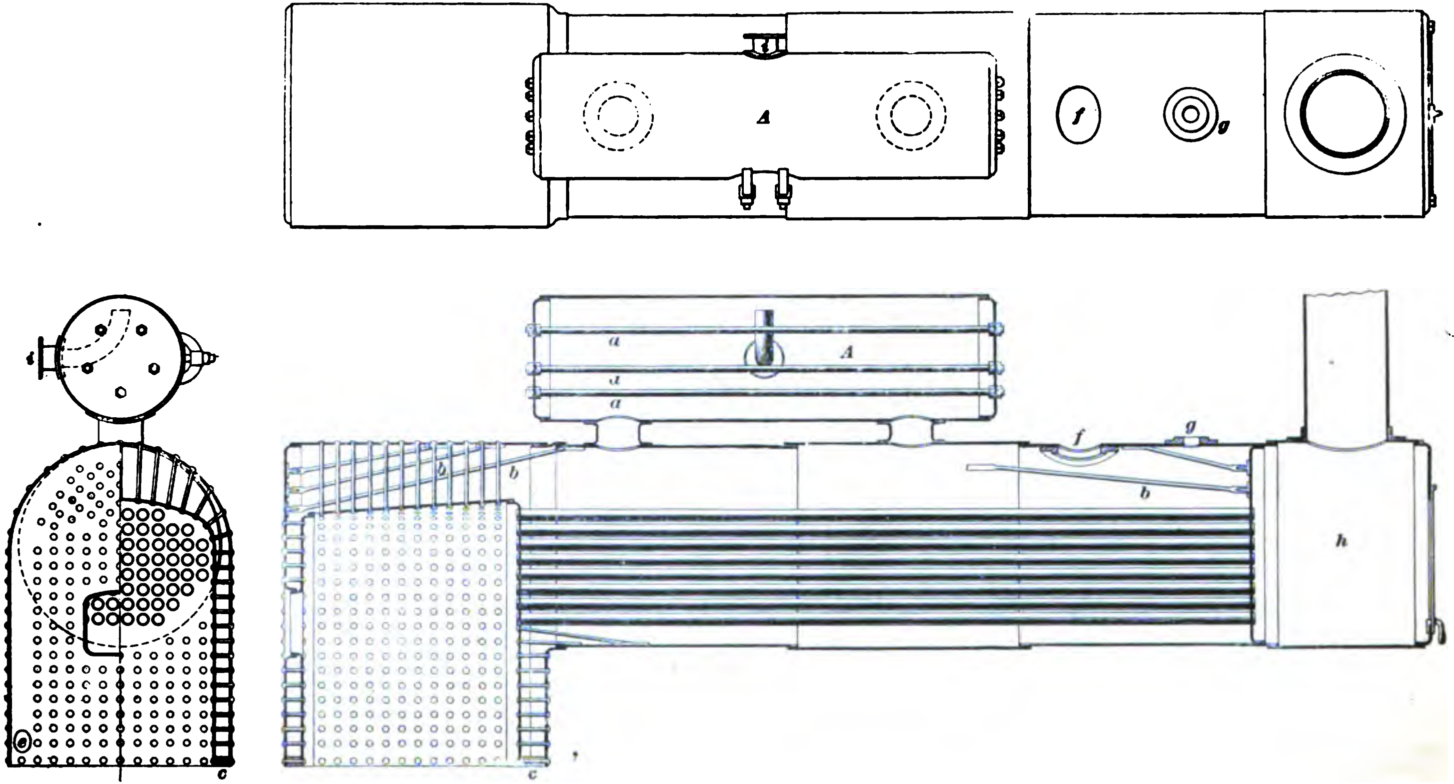


FIG. 25.

nozzle *i* on the side of the steam drum; a curved pipe takes the steam from the top of the drum.

72. There are some other types of boilers in use, but as these are usually merely combinations of some features of one type with some of another type, without possessing any distinctive features of their own, they will not be described here.

THE FLOAT WATER GAUGE.

73. The feed-water used in Western river boilers is usually quite muddy, and as the boilers are forced considerably, a good deal of foaming is found. The ordinary glass water gauge and gauge cocks will not show the true water level when the boiler is foaming, and as this is taking

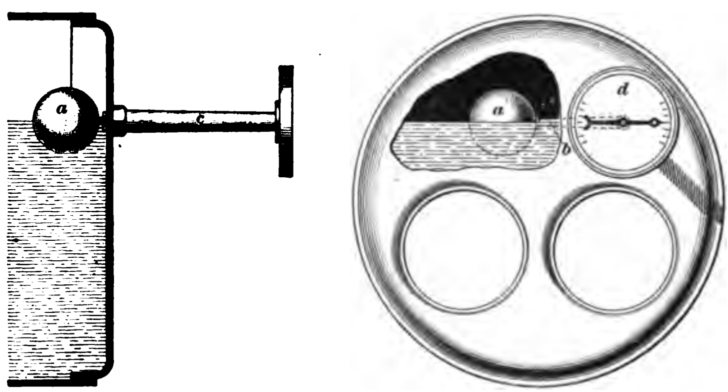


FIG. 26.

place more or less all the time with the bad feed-water used and the high rate of evaporation, it is very desirable to have a water-level indicator which will not be affected by foaming. Hence the float water gauge shown has been designed, and is, in variously modified forms, in common use on the boilers of river steamers, taking the place of the glass water gauge. Fig. 26 is an illustration of such a gauge; *a* is a hollow copper sphere or float, fastened to one end of the lever *b*, which is rigidly fastened to a spindle free to turn in the dial

stem *c*. This stem carries a large dial *d*, graduated as shown. A pointer is fastened to the spindle previously mentioned, and moving in front of the dial, indicates on it the height of water in the boiler. Now, as the float can not float on foam, this gauge will not be affected by foaming, but will always indicate the true water level, provided the spindle moves freely. To make a steam-tight joint between the spindle and boiler, a stuffing-box and gland is employed, and great care must be taken, in packing it, not to pack it too tight. The float must be free to move with any variation of the water level; if the spindle is packed too tight, it may stick and indicate plenty of water in the boiler when it really is dangerously low.

RECENT DEVELOPMENTS IN MARINE ENGINEERING.

REFRIGERATING AND ICE-MAKING MACHINERY.

FUNDAMENTAL PRINCIPLES OF REFRIGERATION.

1. Refrigeration may be defined as the process of lowering the temperature of a body, or of keeping the temperature below that of the atmosphere.

2. Production of Cold.—Cold may be produced by one of the following processes:

1. A transfer of heat from a warmer to a colder body.

2. A chemical action, as exemplified by the so-called freezing mixtures.

3. The adiabatic expansion of a gas. The meaning of adiabatic expansion will be explained farther on.

4. The evaporation of liquids having a low boiling point.

3. Heat will pass from a warmer to a colder body. Drop a hot piece of iron into a vessel of water; then the colder water absorbs some of the heat contained in the piece of iron, and continues to do so until the iron and water are at the same temperature; that is, the heat of the warm body (the hot piece of iron) passes to the cold body (the cool water).

4. In actual practice, ice-making and refrigerating machines employ either of the two last processes in combination with the first. The second process being of no practical applicability will not be considered here.

5. Adiabatic and Isothermal Expansion and Compression.—Let a given volume of any gas under pressure be confined in a cylinder, like that of a steam engine. The gas will then tend to move the piston, i. e., will tend to overcome resistance. If the pressure be sufficient to overcome the resistance, the piston will move and the gas in expanding will be doing work, work being the overcoming of resistance continually occurring along the path of motion of a force. Now, if a thermometer be inserted in the cylinder, it would be found that as the gas expands its temperature is lowered. As is well known, it is not the steam itself which does work in a steam engine, but it is the heat contained in the steam which is converted into work. This statement applies to all other gases as well. Then, as heat must be given up in order to do work, it follows that if no heat is supplied from outside sources, a gas in expanding can not do work without its temperature being lowered. The expansion of a gas, accompanied by a lowering of its temperature directly proportional to the conversion of its heat into work, is known as *adiabatic expansion*. The word "adiabatic" is derived from the Greek word *adiabatos* (*a*, not; *diabainein*, to pass through), and is descriptive of a process in which there is no transfer of heat from or to a body operated upon to or from another body. Conversely, if a given volume of a gas be compressed, its temperature is raised if no heat is abstracted from the gas during compression. That the temperature must become higher can readily be seen when it is considered that it is impossible to compress the gas into a smaller volume without doing work. The process of compression changes this work into heat, i. e., heat is added to the gas, and consequently its temperature is increased. The compression of a gas, accompanied by an increase of temperature directly

proportional to the conversion of the work done in compressing it into heat, is known as *adiabatic compression.*

In other words, a gas is said to expand or to be compressed *adiabatically* when no heat is added to it from an outside source during expansion or abstracted by any medium while the gas is compressed.

Now, let a given volume of gas under pressure expand and do work. As previously explained, it can not do work without parting with an equivalent amount of heat. Let this same amount of heat be added from some outside source. Then, the gas, in expanding and doing work, will remain at a constant temperature, and it is now said to expand *isothermally.* The term "isothermal," which is derived from the Greek (*isos*, equal; *therme*, heat), simply means "at a constant temperature." Conversely, if a given volume of gas at a given temperature be compressed, and the amount of work converted into heat in compressing it be abstracted by some means, its temperature will remain the same. This process is known as *isothermal compression.*

In other words, a gas is said to expand or to be compressed *isothermally* when heat is added during expansion or abstracted during compression, to keep the temperature constant.

6. Now, suppose that a certain volume of gas at a given pressure is allowed to expand *without doing any work.* Then, assuming the vessel in which expansion is taking place to be a perfect non-conductor of heat, so that no heat can be added or abstracted by any outside means, the temperature of the gas during expansion will remain constant; that is, the expansion is adiabatic and isothermal at the same time.

7. The third method of producing cold mentioned in Art. **2** suggests a mechanical process of refrigeration. Let a certain volume of any gas be confined in a cylinder and let it be compressed adiabatically by doing work upon it. When compressed to the smallest volume feasible, reduce the temperature by allowing the heat due to the conversion of work

into heat during compression to pass into a colder body, say cool water. The gas having been cooled to the original temperature, or nearly to it, it can now be made to do work, expanding adiabatically. But in doing work, the pressure and temperature of the given quantity of the gas fall rapidly, and the temperature soon falls far below that of the atmosphere surrounding the machine in which expansion is taking place. Then, as heat will readily pass from a warmer to a colder body, the expanded gas, which is very cold, will, upon being brought near a warmer body, absorb some of its heat, i. e., cool it.

8. It was explained, in connection with the generation of steam, that in order to change water into steam, a certain quantity of heat, called the **latent heat of vaporization,** must be added to the water. This statement applies to other liquids as well. When this process of vaporization or evaporation is taking place in the presence of other warmer bodies, the heat required for it is drawn from these bodies, and they are thereby cooled. From this it follows that if a liquid can be found, the boiling point of which is below the freezing point of water, water can be frozen by allowing the liquid to absorb the heat contained in the water, and thus acquire the heat required for its own evaporation.

There are quite a number of liquids which have a very low boiling point. Some of these will be given later on.

CAPACITY OF REFRIGERATING MACHINES.

9. The **capacity** of a refrigerating machine is the measure of its ability to abstract heat. The unit of **refrigerating or ice-melting capacity** is the quantity of heat required to melt 1 ton (2,000 pounds) of ice at 32° Fahrenheit to water at 32° F. The latent heat of water being 144 British thermal units, the unit of refrigerating capacity is equal to $144 \times 2,000 = 288,000$ British thermal units.

Let F = refrigerating capacity in tons;
H = the number of B. T. U. abstracted per day of 24 hours.

Rule.—*To find the refrigerating capacity of an ice machine, divide the number of B. T. U. extracted in 24 hours by 288,000.*

That is, $$F = \frac{H}{288,000}.$$

EXAMPLE.—A refrigerating machine abstracts 2,375,241 B. T. U. in 20 hours. What is its refrigerating capacity?

SOLUTION.—The heat units that would be abstracted in a day would be

$$\frac{2,375,241 \times 24}{20} \text{ B. T. U.}$$

Then, $$F = \frac{2,375,241 \times 24}{20 \times 288,000} = 9.897 \text{ tons. Ans.}$$

10. Ice-Making Capacity.—The ice-making capacity is the number of tons of ice that a machine is capable of freezing in twenty-four hours. As the temperature of the water from which the machine freezes the ice varies from 50° to 95°, and as it is necessary to cool this water to 32° before any ice can be made, it will be seen that the ice-making capacity is variable and is largely affected by the conditions under which the machine operates. Owing to the necessity of cooling the water from which the ice is made from its initial temperature to a temperature below the freezing point, and owing to other losses, such as radiation, etc., the *ice-making* is only about 50 or 60 per cent. of the *ice-melting* capacity.

11. A refrigerating machine is generally driven by a steam engine; therefore the energy delivered to the machine is contained primarily in the fuel fed to the furnace, usually coal. For this reason, it is customary in commercial work to measure the commercial efficiency, or the *economy* of a refrigerating machine, by the pounds of ice-melting effect per pound of coal used. For every pound of coal consumed in the boiler to produce steam to operate the refrigerating machine, a quantity of heat is abstracted from the cold body sufficient to melt a definite number of pounds of ice at 32° F. into water at 32° F. This quantity of ice is a measure of the commercial efficiency of the machine.

EXAMPLE.—A refrigerating machine having an actual capacity of 23.5 tons requires 4,350 pounds of coal per 24 hours to operate it. Required, the efficiency expressed in ice per pound of coal.

SOLUTION.— 23.5 tons = 47,000 lb.; 47,000 ÷ 4,350 = 10.8; hence 10.8 pounds of ice are melted per pound of coal burned. Ans.

ADIABATIC-EXPANSION REFRIGERATING MACHINES.

AIR REFRIGERATING MACHINES.

Air being the cheapest and most readily obtained gas, it is used considerably for the production of artificial cold. The machines in which it is used are known as air refrigerating machines.

12. The air machine utilizes the fall of temperature that occurs when compressed air expands adiabatically and performs work. The principles underlying the operation of this machine are stated in Art. **7.**

The general arrangement of such a machine is shown in Fig. 1. The machine consists essentially of a compression

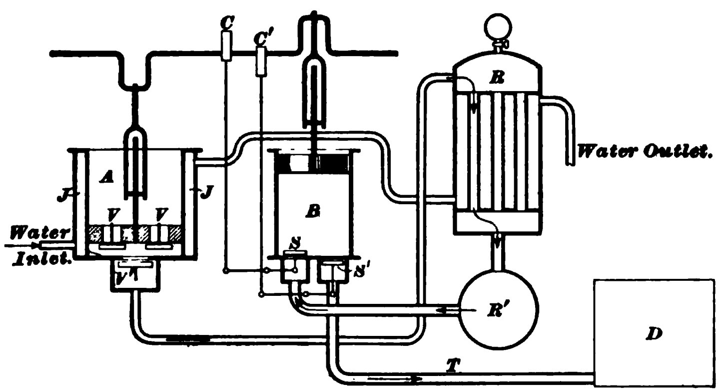


FIG. 1.

cylinder *A*, expansion cylinder *B*, a condenser *R*, and a cooler or refrigerator box *D*. The piston of the cylinder *A* is provided with suction valves *V*, *V*, opening inwards, a

discharge valve *V'*, and also with a water-jacket *J*. The diameter of the cylinder *B* is slightly less than that of *A*. The piston is solid, but the cylinder head is provided with two valves, an inlet valve *S* and an outlet valve *S'*, which are operated by the eccentrics *C* and *C'*. The pistons are connected to cranks set at 180°. The condenser *R* is a surface condenser and receives a current of cold water from the water-jacket *J* of the compression cylinder *A*. A receiver *R'* is connected with the condenser and also communicates with the inlet valve *S* of the expansion cylinder *B*.

The air at ordinary pressure is taken into the cylinder *A* through the valves *V*, *V*, and is compressed abiabatically until the pressure becomes sufficient to open the valve *V'*. The air then passes into the condenser *R*, where it comes in contact with the cold surfaces of that vessel. The adiabatic compression has raised the temperature of the air; but in passing through the condenser, some of the heat contained in the air is given up to the cold water circulating through the condenser, and the temperature is lowered nearly to that of the surrounding air. During this time the valve *S* of the expansion cylinder *B* opens and permits an amount of air equal in weight to that expelled from *A* to pass from the receiver *R'* into the cylinder. The valve *S* closes and the air in the cylinder *B* expands, forcing the piston forwards and doing a certain amount of work. This expansion of the air in the cylinder *B* and the performance of work in forcing the piston forwards is at the expense of the energy stored in the air. The air therefore gives up sufficient heat to do the mechanical work, and as a result its temperature falls. As the air on entering *B* was at a normal temperature, the expansion brings the temperature below that of the surrounding objects. In other words, the air is cooled.

When the piston in *B* reaches the upper limit of its stroke, the valve *S'* opens, and as the piston descends the cooled air escapes by means of the pipe *T* into the refrigerator box *D*.

The difference between the work done on the air in the compression cylinder and that done by the air in the

expansion cylinder, and, in addition, the work required to overcome the friction of the entire machine, must be supplied by a steam engine or other motor.

13. Moisture.—Air at any ordinary temperature can hold a certain amount of water vapor in suspension. The limit, or point of saturation, that is, the point at which the air can hold no more water vapor, is called the **dew point.** When this point is reached, the excess of moisture above that which the air is able to hold is precipitated in the form of dew. The weight of moisture contained in a given volume of air at the dew point is not the same for all temperatures; in fact, air will hold in suspension four times the weight of moisture at 72° that it will at 32°. Assume that the air on entering the expansion cylinder *B* (see Fig. 1) is at a temperature of 72° and is saturated with moisture. As the temperature falls during expansion, the water is gradually precipitated out and condenses on the walls of the cylinder. The water cools as the expansion goes on until it reaches 32°, and then it freezes. The condensation, cooling, and freezing of the water take a great deal away from the useful effect of the machine. Besides, the snow, which is the result of freezing the moisture, often gives trouble by clogging the valves.

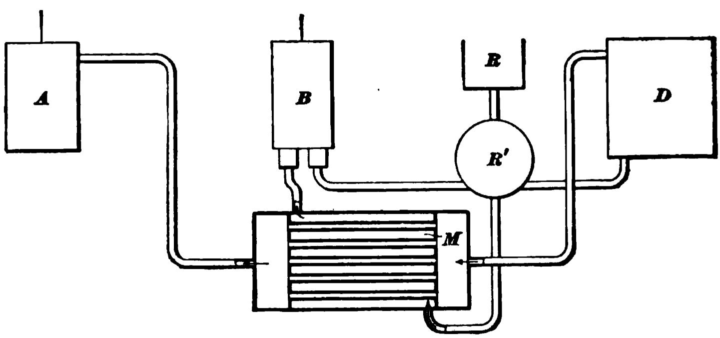


FIG. 2.

14. The Haslam Foundry and Engineering Company, Derby, England, make what is known as a "dry-air" system. They place a *drier* in the suction pipe from the condenser to

the expansion cylinder. The compression cylinder A, Fig. 2, takes the cold air from the refrigerator box D. On its way to A, this cold air passes through the pipes of the drier M. The cold strikes through these pipes and cools the air surrounding the pipes on its way from the receiver R to the expansion cylinder B. The air gives up a large percentage of its moisture in the drier, and the frosting in the cylinder B is much diminished.

THE ALLEN DENSE-AIR ICE MACHINE.

15. This machine, which is used considerably in American steam vessels, differs somewhat from the machine described in Art. **12.** The essential point of difference is that

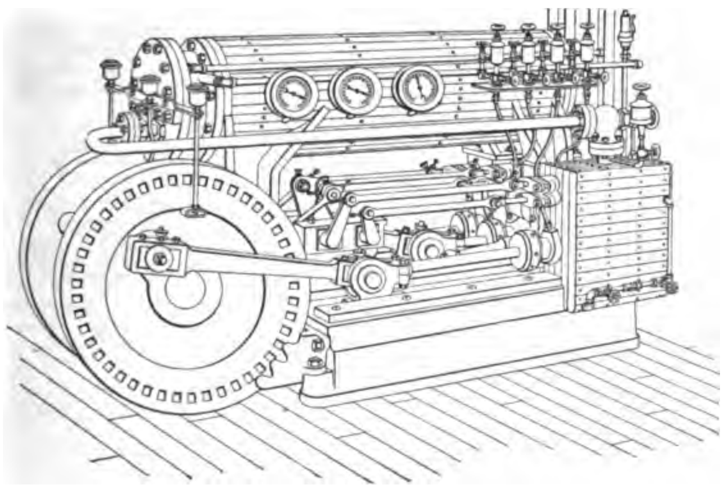


FIG. 3

instead of using air at atmospheric pressure, taken in at every stroke from the surrounding air, it uses air under an initial pressure of about 60 pounds, and uses the same air over and over again. A small supplementary pump attached to the machine charges the system and machine with air at the given pressure, and serves to make up any loss due to leakage. The advantage of using air under pressure is as follows : The amount of heat that a given volume of air can

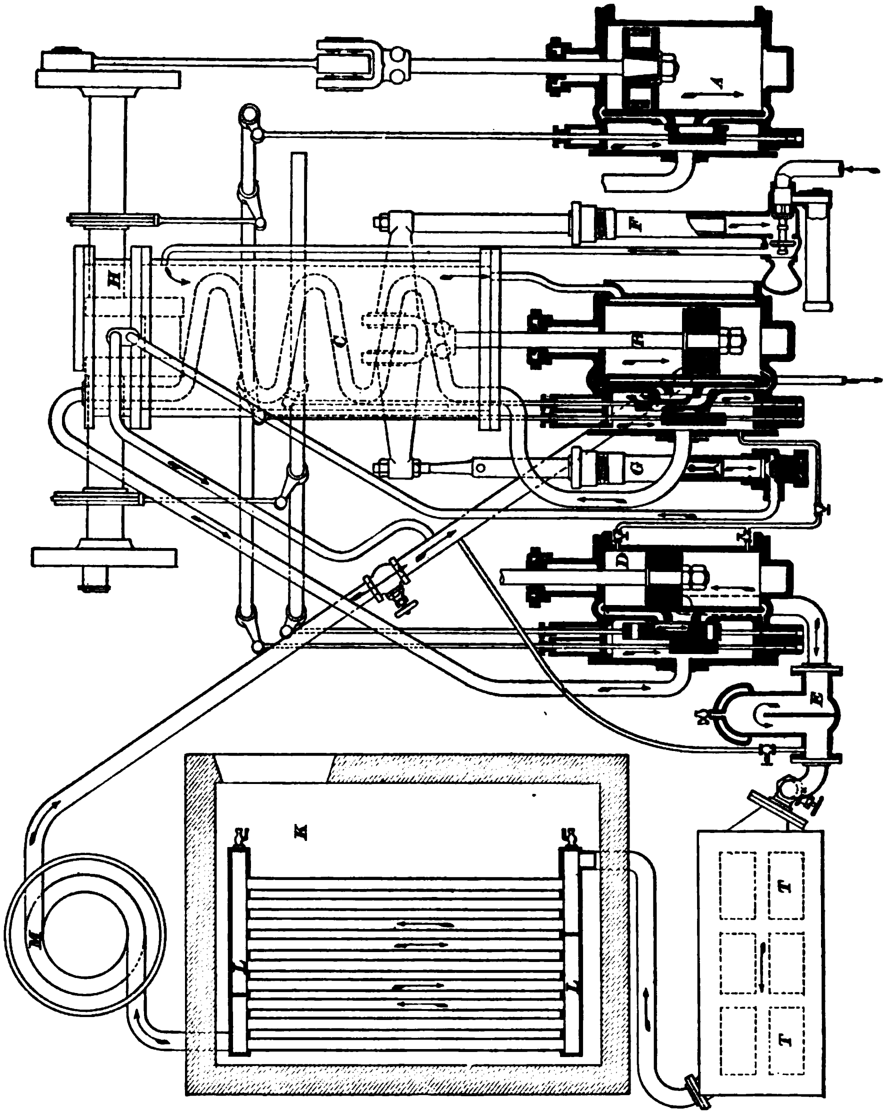


FIG. 4.

abstract from a warmer body varies directly as the weight of the given volume. That is, if a given volume of air weighs 5 pounds, it can abstract five times the quantity of heat from the warmer body than can be abstracted by an equal volume weighing only 1 pound. This allows a smaller conveying pipe to be used, and also allows the machine to be placed at some distance from the refrigerating box or ice-making tank. Naturally, the smaller the pipe conveying the cold air to the refrigerating box, the less surface there is for the absorption of heat from the surrounding air and consequent warming of the cold air; hence, with the small pipe used in this machine, the cold air can be conveyed farther for a given rise of temperature.

16. An outside perspective view of the machine itself is shown in Fig. 3 and a diagrammatic view of a plant in Fig. 4.

The machine consists of the following parts: A steam cylinder *A*, an air compressor *B*, an air expander *D*, a cooler *C*, a water pump *F*, which supplies the cooling water to the cooler, a primer pump *G* for charging the machine with compressed air, and a trap *H*, in which the initial charge of air parts with nearly all of its moisture. The steam piston, air-compressor piston, and expander piston are coupled to the same crank-shaft.

17. The operation of the machine is as follows: On starting up, the primer pump charges the system with air taken from the surrounding atmosphere, compressing it to a pressure of from 60 to 65 pounds. This air, heated by the compression, is discharged into the trap *H*, where it is cooled by coming in contact with the cold head of the cooler *C*. On cooling, it deposits most of its moisture in this trap. The primer pump runs continually, and thus keeps up the initial pressure; any excess of air beyond that required is discharged through a small safety valve. From the trap the compressed and cooled air passes into the double-acting air compressor *B*, where the initial charge is compressed to a pressure of from 210 to 225 pounds. The heat is abstracted from the air

by passing it through a copper coil inside of the cooler *C*, through which the cooling water taken from the sea is constantly circulated by the pump *F*. The air under high pressure is here cooled to nearly the temperature of the cooling water, and passes from the cooler to the expander cylinder, where it is cut off at $\frac{1}{3}$ of the stroke, and in expanding does work. Its temperature is thus lowered to from 35 to 55 degrees below zero Fahrenheit. The expanded cold air, which is now at a pressure of from 60 to 65 pounds, then passes into an oil trap *E*, where it parts with most, if not all, of the lubricating oil used in the compressor and expander. All snow, due to unremoved moisture in the air, is gathered here. This trap is steam-jacketed; the steam is turned on, however, only when it is desired to remove the frozen oil and the snow from the trap. The air now passes through coils of pipe in the ice box *T* and refrigerating room *K*; the coiis in the refrigerating room are shown at *L*. From there it passes through the drinking-water butt *M* and returns to the compressor inlet. By passing the cold air through coils, a large heat-absorbing surface is provided; in its passage through these coils, the cold air absorbs the heat of the warmer air surrounding the coils, and thus cools it. Naturally, the cold air becomes warmer.

18. In some instances the return air, which is still quite cold, is passed through a special cooler, where it cools the highly compressed air coming from the cooler *C*, thus furnishing the expander cylinder with cooler air than could be obtained otherwise. If this is done, according to the builder, a temperature of from 70° to 90° below zero Fahrenheit is obtained.

19. Directions for Running the Allen Machine.—Warm up the steam engine. Open the suction valve and discharge valve of the circulating pump. See that the two valves in the main pipes are open, and that the valve of the by-pass pipe connecting the return-air pipe with the cold-air pipe is closed. Open the blow valves of the expander cylinder and the pet-cocks of the traps. Start the machine.

When no more grease or water discharges from the various pet-cocks, close them. Be sure that the circulating water is in motion.

During running, open the pet-cocks of the water trap *H* frequently enough to allow the water collected there not to fill it more than half full. Once or twice a day the machine should be cleaned by heating it and blowing out all oil and deposits. This is done as follows: First open the valve in the by-pass pipe. Then close the two valves of the main pipes. Open the valves in the hot-air pipe leading from the valve chest of the compressor to the expander cylinder, and partially close the valve of the expander inlet pipe. Turn the live steam on the jacket of the oil trap, opening the outlet of the jacket just enough to drain off the condensed steam. Run in this manner for about half an hour, and during this time frequently open the blow-off valves of the oil trap and expander, and continue to do so until the trap and expander are clear. Then shut off the steam from the jacket of the trap, drain the connections, close the valves in the hot-air pipe leading from the compressor to the expander, close all pet-cocks, open the valves of the main pipes, and close the by-pass valve. The machine will now generate cold as usual. When a pressure of from 60 to 65 pounds can not be retained in the system, it indicates a leakage of air somewhere. It is usually found at the stuffing-boxes, which should then be tightened up or repacked. If the compressor does not keep up its usual pressure in relation to the initial pressure, it shows that there is either a leak from the high-pressure to the low-pressure part of the system or to the atmosphere, or it may be due to the cup-leather packing of the compressor and expander cylinder having given out. The failure to maintain the high pressure will result in a higher cold-air temperature. The cup leathers should be made of white oak-tanned leather well soaked in castor oil. They will last from one to two months in steady use. The sight-feed lubricators for the compressor and expander cylinders should be filled with a light, pure mineral machine oil from which all paraffine has been removed. Use about 3 drops

of oil per minute in the compressor and 2 drops in the expander. The makers of this machine recommend Leonard and Ellis Extra Machine Oil for this purpose.

Whenever the pipes of the manifolds in the refrigerating room, ice tank, etc., are thawed out, drain them. Never omit to do this when you have the opportunity.

LATENT-HEAT REFRIGERATING MACHINES.

FLUIDS USED AS REFRIGERATING AGENTS.

20. The air refrigerating machine produces its refrigerating effect by means of the fall of temperature incident to adiabatic expansion. In all other refrigerating machines, the abstraction of heat is brought about by the vaporization of some liquid having a low boiling point. Such machines may be classed as **latent-heat** refrigerating machines.

21. Theoretically, any volatile liquid may be used as a working fluid in a latent-heat machine; there are, however, various considerations of a practical nature that govern the choice of the liquid. The chief requisites of the fluid used are:

1. It should vaporize at a low temperature when at ordinary atmospheric pressure.
2. It should have a high latent heat.

The fluids that have been used in compression machines are ether, sulphur dioxide, anhydrous ammonia, and Pictet fluid.

22. Table 1 gives the boiling points and latent heats of various substances at atmospheric pressure, 14.7 pounds per square inch.

Under a pressure of 342 pounds per square inch, carbon dioxide boils at a temperature of 5°. Its latent heat under the same conditions is 121.5.

23. Ether.—Early in the history of ice-making and refrigerating machines, ether was almost universally used

TABLE 1.

Substance.	Temperature of Boiling Point.	Latent Heat, B. T. U.	Specific Heat of Liquid.
Nitric Acid	248° F.	....	....
Saturated Brine	226° F.	....	....
Water	212° F.	966	1.0000
Alcohol	173° F.	....	....
Chloroform	140° F.	....	....
Ether, Sulphurous	95° F.	170	.5299
Ether, Methyl	– 10° F.	....	....
Sulphur Dioxide	14° F.	168.7	.4100
Anhydrous Ammonia	– 28.5° F.	573	1.0058
Carbon Dioxide	– 140° F.	121	.9950

as the working fluid. This was due to its high condensing temperature and consequent low condensing pressure. This low condensing pressure made it possible to use compression pumps of ordinary construction, very much after the style and pattern of air pumps. However, the disadvantages in the use of ether were found to be very great; the first cost of ether is considerable; but the great objection to it is its inflammability and its liability to explode when mixed with air. Furthermore, owing to the density of the vapor at the required working pressure, the compression cylinder must be very large, viz., 6 times larger than for sulphur dioxide and 17 times larger than for ammonia.

24. Sulphur Dioxide.—The objections to ether led to further investigation. Sulphur dioxide was found to be more efficient than ether, for though it required a higher condensing pressure, it did not require to be evaporated under a vacuum. Consequently the compression pumps were made somewhat smaller for a given capacity, but were built stronger and more attention was given to the

elimination of clearance spaces. The temperatures produced with sulphur dioxide, though lower than those obtained with ether, were not sufficiently low.

25. Pictet Fluid.—It was found by Prof. Pictet, a Swiss physicist, that a mixture of 97% of sulphur dioxide and 3% carbon dioxide, commonly known as carbonic-acid gas, gives a boiling point 14° F. lower than pure sulphur dioxide. This liquid, or rather mixture, has been since known as **Pictet fluid.** Its latent heat has never been closely determined, but is very nearly the same as that of pure sulphur dioxide.

26. Carbon Dioxide.—This liquid has the lowest boiling point of any of the fluids employed in refrigeration. Under a gauge pressure of 200 pounds per square inch it will have a temperature of about − 22° F. Its condensing pressure is correspondingly high, being about 900 pounds per square inch for a water temperature of 70° Fahr., for which reason its use alone has been found impracticable.

27. Ammonia.—One atom of nitrogen combines with three atoms of hydrogen to form one molecule of **ammonia ;** this is the only combination of these two elements. The ordinary ammonia of commerce is a *solution* of ammonia gas in water, and is properly known as **aqua ammonia.** The gas which passes off from the aqua ammonia is the ammonia formed by the combination of nitrogen and hydrogen. When this gas is *entirely free* from vapor of water it is called **anhydrous**-ammonia gas

28. Ammonia gas, when liquefied under a high pressure and allowed to evaporate under atmospheric pressure, gives a temperature of 28.5° F. below zero. Liquid anhydrous ammonia, when subjected to a temperature of − 115° F., freezes and forms a solid. In this state it is almost odorless and is heavier than the liquid.

Ammonia has no effect on either iron or steel, but rapidly corrodes copper and brass. It is therefore necessary to make the parts of ammonia machines out of the former metals.

At a temperature of 900° F. the gas is resolved into its constituent elements. But it is probable that this dissociation occurs to a limited degree at much lower temperatures.

Ammonia is not inflammable at ordinary temperatures, but if mixed with oxygen will burn with a pale-yellow flame. The liquid will not explode, but when run into drums or flasks, room should be left for expansion. Like almost all liquids, ammonia expands when heated, and if sufficient space is not left for expansion, the flask is likely to burst if exposed to a high temperature.

The latent heat of vaporization of ammonia is much greater than that of other fluids. This property makes ammonia especially valuable as a refrigerating agent, because, on account of the high latent heat, a greater refrigerating effect per pound of fluid circulated can be obtained with ammonia than with the other agents.

29. Aqua Ammonia.—As already stated, aqua ammonia, known also as ammonia liquor, is a solution of ammonia gas in water. At 32° F. and under atmospheric pressure, water will absorb 1,140 times its volume of ammonia gas. The amount of gas held in solution affects the specific gravity of the solution; the more gas absorbed the less the density. The amount of ammonia that can be absorbed by water is governed by the temperature of the water and the pressure of the gas. The colder the water and greater the pressure, the greater the quantity of ammonia taken up.

30. The strength of a solution of anhydrous ammonia in water is measured by an instrument called a **hydrometer,** which is used for determining the densities of various liquids. It differs from the salinometer only in being differently graduated. When this instrument is placed in a liquid, it is evident that it will sink deeper the less the density of the liquid; hence the density will be indicated by the mark on the scale at the level of the liquid. For liquids lighter than water, the point to which the instrument sinks when placed in a solution of 10 parts of salt to 90 of

water is marked 0°, and the point to which it sinks in distilled water is marked 10°. The space between the two marks is divided into 10 parts and the division is continued to the top of the stem. The hydrometer thus graduated is generally used for ammonia solutions, though there is another graduation in which the reading for pure water is 0° instead of 10°.

TABLE 2.

STRENGTH OF AMMONIA LIQUOR.

Percentage of Ammonia by Weight.	Specific Gravity.	Degrees on Hydrometer.	
		Water 10°.	Water 0°.
0	1.000	10.0	0.0
1	.993	11.0	1.0
2	.986	12.0	2.0
4	.979	13.0	3.0
6	.972	14.0	4.0
8	.966	15.0	5.0
10	.960	16.0	6.0
12	.953	17.1	7.0
14	.945	18.3	8.2
16	.938	19.5	9.2
18	.931	20.7	10.3
20	.925	21.7	11.2
22	.919	22.8	12.3
24	.913	23.9	13.2
26	.907	24.8	14.3
28	.902	25.7	15.2
30	.897	26.6	16.2
32	.892	27.5	17.3
34	.888	28.4	18.2
36	.884	29.3	19.1
38	.880	30.2	20.0

In the above table, the first column gives the number of parts of ammonia gas in 100 parts of the solution; the

second column gives the specific gravity of the solution; and the third column gives the corresponding reading on the hydrometer. For example, if the hydrometer reading is 16°, the solution consists of 10 parts, by weight, of ammonia to 90 parts of water, and the specific gravity of the solution is .960.

31. Heat of Absorption.—All chemical actions as well as solutions and absorptions are accompanied by an increase or decrease in the temperature of the mixture. This is especially true of absorptions. In the case of ammonia absorbed in water, 925.7 B. T. U. are given up for each pound of ammonia gas absorbed under atmospheric pressure. Though no very exhaustive experiments have been made on this subject, results deduced from the practical running of refrigerating machines show that this figure is practically constant.

Since heat is given up when ammonia gas is absorbed, heat will be absorbed when the gas is again liberated from the water. The quantity of heat necessary to liberate 1 pound of anhydrous gas is 925.7 B. T. U., the same amount of heat that is given out by the liquid when the gas is being absorbed.

32. Tests for Ammonia.—If it is desired to test the purity of liquid anhydrous ammonia, draw some out into a flask having a cork with a bent tube inserted in it. Wrap the flask up in dry waste or cloth before drawing off the ammonia, or the fingers are liable to be frozen fast to the flask. The liquid ammonia evaporates slowly, the gas passing out of the bent tube. If an accurate low-temperature thermometer is obtainable and is immersed in the boiling liquid, it should indicate a temperature of $-28.5°$ F., with normal barometric pressure. If the liquid is pure anhydrous ammonia, there should be no residue left in the flask. A deposit of oil or water indicates impure ammonia.

To detect a leak in piping in case the odor does not betray it, hold a glass rod moistened with muriatic acid near the

supposed leak. A white fume rising from the rod indicates an escape of ammonia.

To detect ammonia leaks in piping under water or brine, add to a sample of the suspected liquid a few drops of *Nessler's reagent;* a yellow coloring indicates traces of ammonia, but if the quantity of ammonia is large, the color changes to a dark brown.

33. To Prepare "Nessler's Reagent."—Dissolve 0.6 oz. of mercuric chloride in about 10½ oz. of distilled water; dissolve 1¼ oz. of potassium iodide in 3½ oz. of water; add the former solution to the latter, with constant stirring, until a slight permanent red precipitate is produced. Next dissolve 4¼ oz. of potassium hydrate in about 7 oz. of water; allow the solution to cool; add it to the above solution, and make up with water to 35¼ oz., then add mercuric chloride solution until a permanent precipitate again forms; allow to stand till settled, and decant off the clear solution for use; keep it in glass-stoppered blue bottles, and set away in a dark place to keep it from decomposing.

34. The density of the gas at the evaporating temperature and the latent heat of the liquid determine the size of the compression cylinder necessary for any required capacity. The same machine working between 5° and 64.4° will give the following cooling effects per *cubic foot* of compressor-piston displacement under theoretically perfect conditions:

Carbon dioxide	248.18 B. T. U.
Ammonia	62.75 B. T. U.
Sulphur dioxide	22.88 B. T. U.
Sulphuric ether	3.68 B. T. U.

THE AMMONIA-COMPRESSION SYSTEM.

35. General Description.—Suppose a flask or ordinary bottle *B*, Fig. 5, supplied with a cork having a bent tube *G* inserted, is partially filled with anhydrous ammonia. This can be done easily, as the evaporation of the ammonia is comparatively slow, owing to its high latent heat. As

the ammonia enters the flask, frost will begin to gather on the outside. If now we place this flask into a pail A, partially filled with water C, in a short time ice D will begin to gather on the outside of the flask. This is the simplest form of ice machine, but in this form the liquid ammonia, when it evaporates, passes out of the flask and is lost.

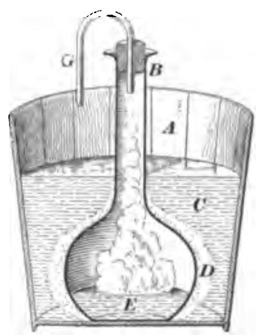


FIG. 5.

As with all volatile vapors, the temperature at which vaporization (or condensation) occurs rises as the pressure of the vapor increases. To prove this, insert a thermometer into the flask so that the bulb is immersed in the boiling ammonia. The temperature will fall rapidly, and if the thermometer is correct should register 28.5° below zero. Take a piece of pipe; weld or plug one end and fit the other with a cap B, Fig. 6. Arrange a stuffing-box C about the thermometer T in the cap. Also provide an opening connecting with the pressure gauge P. Unscrew the cap and pour the contents of the flask into the pipe A, and screw on the cap B. If the gauge points to zero, the thermometer should still read $-28.5°$ F. Watch the gauge and thermometer carefully. The ammonia evaporating in the pipe liberates gas. As this gas can not escape, it creates a pressure in the pipe, which will be shown on the gauge, and a corresponding increase in the temperature of the boiling ammonia will become apparent. This will continue until the temperature of the liquid will be identical with the surrounding objects. Assume this temperature to be about 70° F.; the gauge should then show a pressure of 130 pounds per square inch. If, therefore, we keep the temperature of the pipe at 70° by immersing it in water at that temperature, and arrange to keep a pressure slightly in excess of 130 pounds per square inch in the pipe, no further evaporation will take place, and the remaining liquid ammonia will lie quietly in the pipe.

36. From the foregoing it is apparent that if some means be devised of taking the evaporating gas as it leaves the flask in Fig. 5 and transferring this gas into the pipe of Fig. 6, it would be possible to save the gas. In place of a short piece of pipe *A*, Fig. 6, take a large coil of pipe *A*, Fig. 7, submerged in a tank of water *C*. The water enters by means of the pipe *F*, and the overflow passes out of the pipe *F'*; the continuous flow tends to keep the temperature of the coil *A* constant Replace the flask *B* in Fig. 5 with a coil of pipe *B*, Fig. 7, immersed in a water tank *D*. Provide a pump capable of working against a high pressure, and connect the suction of the pump with the coil *B*, and the discharge with the coil *A*. Also provide pressure gauges *G'* and *G* on each of these lines. Connect the bottom of the two coils together, and place a valve *E* in the line. Partially fill the coil *A* with anhydrous ammonia. If the temperature of the water in *C* is about 70°, the gauge *G'* will show a pressure of 130 pounds. Open the valve *E* slightly, and leave it open. The pressure denoted by the gauge *G* will gradually rise, and ice will begin to form on the lower pipes of *B*. When the pressure shown by *G* has reached 15 pounds, start the pump *P*. This pump will draw the gas out of the coil *B*, compress it and deliver it to the coil *A*. The gas entering *A*, which has been heated by the compression, comes in contact with the cold pipe surface, and is first

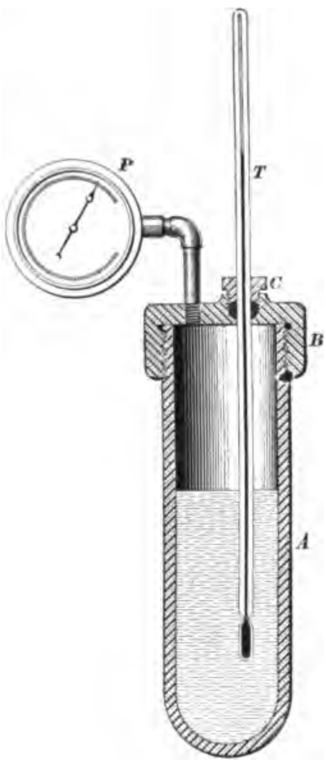


FIG. 6.

cooled until its temperature is but little above that of the condensing water flowing out through F'. The gas then condenses and falls to the bottom of the coil in the form of liquid anhydrous ammonia. As the valve E is open, the coil A is prevented from filling up. The withdrawal of a

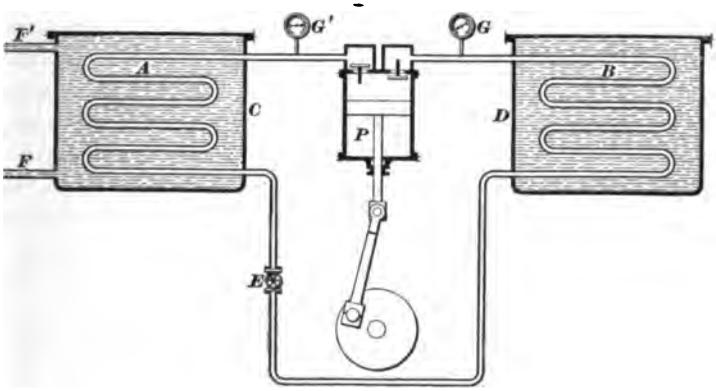


FIG. 7.

quantity of the gas in the coil B tends to decrease the pressure in that coil; however, a quantity of the liquid passes from A to B, through the expansion valve E, vaporizes, and supplies an amount of gas equal to that withdrawn by the pump.

37. Heat of Compression.—If ammonia vapor is compressed adiabatically, it will be superheated, and the work done on the vapor by the piston will be stored up in the vapor in the form of heat. This heat must be gotten rid of during the period of compression, otherwise it must be absorbed by the condensing water before the vapor condenses. It is quite evident that it will be most economical to remove the heat, as far as possible, as fast as it is generated, and keep the temperature of the cylinder comparatively low throughout the compression. In fact, it is absolutely necessary to employ some method of keeping the cylinder cool, otherwise the excessive heat developed in compression would soon become so great that the gas would

enter the cylinder in a greatly superheated state, which would lessen its density. This decrease in density would naturally cause a corresponding decrease in the weight of gas pumped in a given time, thus affecting both capacity and economy.

A number of expedients have been tried with this object in view. The simplest of these is jacketing the cylinder with water. This method of cooling the compression cylinder is known as the **dry-compression system.** The gas enters the cylinder in perhaps a saturated state, though usually somewhat superheated; the instant that compression begins, however, the vapor is immediately superheated.

In the second method, **wet compression,** the cylinder is not jacketed, but a certain amount of liquid anhydrous ammonia is allowed to enter the cylinder with each stroke of the compressor; the mixture of vapor and liquid remains saturated while it is compressed, the heat equivalent of the work of compression is taken up by the vaporization of a part of the liquid, and the vapor remains at the temperature due to the pressure.

The third method employed is a modification of wet compression. Instead of permitting anhydrous ammonia to enter the cylinder, a certain quantity of oil is injected during the stroke; the purpose of the oil is to cool the gas during compression and seal the valves so as to cut down the clearance space.

38. Dry Compression.—The majority of compressors built in the United States are of the water-jacketed, dry-compression type. In the case of vertical compressors, the water-jackets are merely small tanks enclosing the walls of the cylinder, and are sufficiently high so that the top head of the cylinder is also immersed. They are open at the top and the water passes off by gravity. Horizontal compressors are usually water-jacketed on the cylinder walls only, the heads being unjacketed.

39. Wet Compression.—The injection of a small quantity of anhydrous ammonia to cool by its evaporation

the walls of the cylinder was the invention of Professor C. P. G. Linde, of Munich, Germany. The machines built under this system bear his name and are of the horizontal, double-acting type. The temperature of the gas leaving the compressor in case of the Linde machine is much lower than that in the dry-compression system, and the theoretical economy is somewhat higher than that of the latter system. An objection sometimes urged against wet compression is the necessity of introducing a small quantity of liquid ammonia, which if increased in any degree by carelessness is liable to act somewhat like water carried over in the steam of a steam engine, and may break the cylinder head. The chances of such an occurrence are so small that the objection does not appear to be a serious one.

40. Oil Injection.—The third method of cooling the cylinder during compression is that of the De La Vergne Company. In the earlier machines a small quantity of oil was admitted into the compression cylinder during suction and was expelled at compression. The mixture of oil and gas at a somewhat high temperature passed to the oil separator, where the oil was separated from the ammonia gas. The gas passed on to the condenser in its regular cycle; the oil was taken from the separator, passed through a cooling coil immersed in running water, and was then allowed to run into a receiver, from which it again passed into the suction pipe.

It will be seen from this description that as a certain quantity of oil was allowed to enter with the gas, the volume of the gas entering the cylinder at each stroke was decreased in proportion to the amount of oil injected; in case a considerable quantity of oil was fed in, this would cut down the capacity appreciably. In order to obviate this difficulty, the De La Vergne Company in their new compressors inject oil by means of a small pump after the work of compression has set in, and not during suction as formerly. This also permits the oil to be kept fully charged with ammonia.

THE AMMONIA-ABSORPTION SYSTEM.

41. General Description.—The action of a refrigerating system of the absorption type is based upon the affinity of a vapor, usually ammonia vapor, for water. Water will absorb 1,140 times its volume of ammonia gas, and to liberate 1 pound of ammonia gas thus absorbed requires the expenditure of 925.7 B.T.U. Suppose we have a strong solution of aqua ammonia; if heat be applied to the solution, the ammonia gas or vapor will be driven off at relatively high pressure, and when passed through a condensing coil will condense to the liquid state. The liquid can now, just as in the compression system, be admitted to a refrigerating coil through an expansion valve. In this coil it will vaporize and withdraw heat from the surrounding objects. The vapor may now be again absorbed by water, thus regaining its original state and closing the cycle of operations.

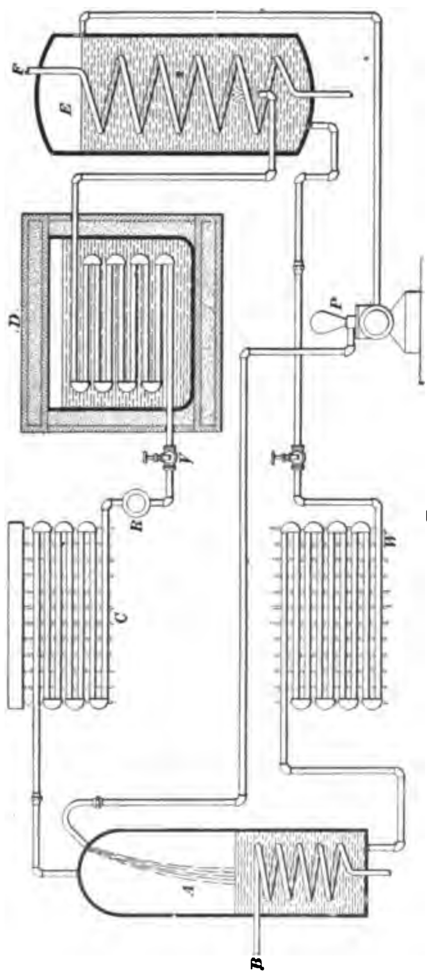


FIG. 8.

42. The essential features of the absorption system are shown in Fig. 8. Steam is admitted at a pressure of about 40 pounds per square inch, gauge, to a coil *B*, submerged in a strong solution of aqua ammonia, contained in the vessel *A*. The temperature of the solution will be raised nearly to that of the incoming steam, say to about 270° F., and the heat absorbed will cause the ammonia gas to be driven off at a pressure of say 160 pounds per square inch.

As the temperature of the solution is below the boiling point of water for this pressure, no water will evaporate, and only ammonia gas will pass over into the condenser *C*. The cold water flowing over the condensing coils absorbs heat from the gas, and the combined effect of the high pressure and the cooling action of the water is to liquefy the gas. It is to be noted that the pressure is not produced mechanically, as in the compression machine, but by chemical action.

As the ammonia liquid passes through the expansion valve to the expansion coils, the pressure is reduced, reevaporation begins in the expansion coils, and heat is absorbed from the brine or other substance in the tank *D*.

In the compression system the ammonia pump draws the gas from the expansion coils, but in the absorption system the removal of the gas is effected by allowing the gas from the expansion coils to mingle with the weak solution of ammonia from which the gas was expelled in the **still** or **generator** *A*.

During the process of generating the ammonia gas in the still *A*, the strong solution rises to the top on account of its smaller specific gravity, and the weaker solution settles to the bottom and flows through a pipe to the vessel *E*, called the **absorber.** Here it meets the gas as it comes from the expansion coil and absorbs it. Since a low temperature is required for efficient absorption, the weak liquor on its way to the absorber passes through a coil *W*, which is cooled by running water. The absorber *E* is also provided with a water coil *F*. A small pump *P* takes the strong liquid from near the top of the absorber and forces it back into the generator. This completes the cycle of operations.

H. M. II.—19

APPLICATION OF REFRIGERATION.

REFRIGERATING SYSTEMS.

43. There are two principal systems of refrigeration, viz., the **brine** system and the **direct-expansion** system.

In the former system the expansion coils are immersed in a tank of brine; this brine, which is a non-freezing solution of salt, gives up its heat to the ammonia evaporating in the coils or to the cold air passing through the coils, and is then pumped through coils of pipe placed on the sides or ceiling of the room to be cooled. The circulating brine thus continually absorbs heat from the cold room and gives it to the ammonia or air.

44. In the direct-expansion ammonia and air system, the ammonia or air is admitted directly into the coils in the rooms to be refrigerated. The heat of the cold room is taken up by the ammonia or air directly, and the intermediate agent, brine, is not employed. The difference between the two systems may be explained as follows: In Fig. 7, suppose the expansion coil *B* to be a comparatively short or compact coil, and let the vessel *D* be a tank containing brine; with this arrangement, we have the brine system. On the other hand, suppose the vessel *D* to represent the room or rooms to be cooled, and suppose the expansion coil *B* to be a long coil divided into many branches and located on the ceilings or sides of the rooms; this arrangement constitutes the direct-expansion system.

In another direct-expansion air system, the cold air is led through suitable chutes to the rooms to be cooled, and is discharged directly into the room. The air-compressor draws its air supply from these rooms.

VARIETIES AND PROPERTIES OF BRINE.

45. Salt Brine.—There are two salts commonly used for making the brine used in brine circulation. The first is Liverpool salt (chloride of sodium), which forms the ordinary brine capable of withstanding a temperature of about 0° F. This salt is cheap in first cost, but has corrosive action on iron.

46. Chloride-of-Calcium Brine.—The other salt used for making brine is the chloride of calcium. It possesses all the properties which the ordinary salt does not. It has no corrosive action on iron, which makes it unnecessary to have the brine pump lined with brass. It has, in fact, an oily nature, and for that reason has a strong tendency to leak if the piping is in any way imperfect; care should therefore be exercised in the pipe work of a chloride-of-calcium brine circulation. It is possible to obtain much lower temperatures by the use of chloride of calcium than common salt brine, $-50°$ F. being the limit.

The cost of chloride of calcium is about double that of salt. The quality is extremely variable; insist upon having *fused* chloride of calcium. The salt is excessively deliquescent, that is, it is capable of absorbing a large quantity of water; for this reason it is often used as a drier. This great avidity of calcium chloride for water renders adulteration by the absorption of water very easy. Even the fused salt contains as much as 20 per cent. of water, whereas the unfused salt, though still in solid form, contains upwards of 50 per cent. of water. Care should, therefore, be used in selecting the salt.

When it is desired to purchase chloride of calcium, request samples. Dissolve a certain weight of each sample of the salt in the same quantity of water; take a hydrometer reading of each one of the samples after the salt is thoroughly dissolved; the one giving the highest reading is the best sample.

To make chloride-of-calcium brine, use about equal weights of water and chloride of calcium. Whenever it is observed that the brine commences to freeze, add a little chloride of calcium, stirring it well into the brine.

THE RUNNING OF REFRIGERATING MACHINES.

STARTING UP A COMPRESSION MACHINE.

47. The brine having been prepared, the machine charged with ammonia, and all connections tested, the apparatus is ready for service. Before any cooling is possible in the refrigerating room, it is necessary to cool the brine

charge below the freezing point. The brine pump being stopped, the water pump is started and water is run over the condensers and through the water-jacket of the compressor. As the temperature of the brine is probably in the neighborhood of 55°, a comparatively high back pressure can be kept in the expansion coils. As the compressor is started when the pressure in the expansion coils is comparatively high—100 to 150 pounds—it is necessary to reduce this pressure to 30 or 40 pounds before the brine shows any perceptible cooling. The main suction and discharge valves are opened, the by-pass valves are closed, and the compressor is started. The back-pressure gauge will begin to indicate less and less pressure. When a pressure of 30 pounds is reached, the expansion valve is slightly opened, and care is taken to regulate it so as to keep the back pressure between 30 and 35 pounds. After some time the brine temperature will have fallen to about 25°.

The brine pump can now be started. This will start the circulation in the refrigerating room and also that in the brine tank, which will help to cool the brine more rapidly. The expansion valve can be closed a little, so that the back pressure will drop gradually as the temperature of the brine falls. The machine is now in full operation.

If at any time the compressor cylinder begins to groan, some oil should be pumped into the suction pipe. Care should also be taken that the piston-rod packing is well lubricated; if it begins to heat, the gland on the stuffing-box should be slackened and some oil pumped in. This will cool the rod. It is better to have the piston rod leak a little the first day or two than to have the packing so tight as to cut the rod.

48. Expansion.—When the brine has cooled to a temperature of 15°, an inspection of the charge should indicate at least 6 inches of liquid anhydrous ammonia in the receiver of the condenser and a back pressure of 20 to 25 pounds. If, however, the back pressure is lower and there is a small quantity of anhydrous ammonia in the receiver, a drum containing liquid anhydrous ammonia should be connected up and its contents pumped into the machine.

There is usually one main expansion valve and a number of feed valves, one on each coil, for the purpose of regulating the amount of anhydrous ammonia being fed to the separate coils. These valves should be adjusted once for all, so as to proportion the amount of anhydrous ammonia supplied to each coil; then they should be left alone. The total amount of anhydrous ammonia expanded should be regulated by the main expansion valve. If the compressor is working properly, the whole action of the machine hinges on the proper manipulation of the expansion valve. A low back pressure is detrimental to the economical working of a compression machine. Therefore, care should be taken to carry as high a back pressure as possible, and at the same time avoid overfeeding. The best indication of overfeeding is a heavy frost on the suction pipe of the compressor. Not all the liquid anhydrous ammonia is evaporated in the expansion coils, and, consequently, some of it passes over to the compressor. The evaporation in the suction end of the cylinder causes the packing of the piston rod to freeze, and it is liable to leak as soon as it thaws out again. The greatest danger from overfeeding, however, arises from liquid ammonia or oil entering the cylinder of the compressor. The liquid being incompressible, its presence may result in the breakage of a cylinder head or of a shaft, or the derangement of some part of the compressor. The action in this case is the same as that of a steam engine taking water in with the steam.

49. Shutting Down the Machine.—To shut down a compression machine the main throttle valve of the steam engine is closed, care being taken that the compressor does not stop on a dead center. The valve on the oil feed is then closed, together with the main suction and delivery valves and the expansion valve. The other valves may be left open. The water pump is then stopped and all the drips are opened; the same is done with the brine pump. The refrigerating plant is now shut down, and the steam plant may be shut down as in ordinary practice.

STARTING AN ABSORPTION MACHINE.

50. After the air and other gases have been expelled from the absorber, the ammonia pump is started, and the steam is gradually turned on to the generator. When a pressure of 120 or 130 pounds has been reached, the valve leading to the condenser is opened and the water is turned on to the condenser and absorber. This valve should be opened slightly, so as not to create too strong a current between the condenser and the generator, as the difference between the pressures in these two vessels may be considerable. The generator pressure now extends to all the high-pressure parts of the machine. The expansion valve is then opened a very little until the gauge indicates 15 to 20 pounds, As soon as the liquor is seen in the gauge glass of the absorber, the suction valve and the delivery valve of the ammonia pump are opened and the ammonia pump is started. The pump is run at such a rate as to keep the liquor in the gauge glass on the absorber at a constant level. The machine is now doing regular work, cooling the brine in the brine tank.

THE TEMPERATURE REQUIRED BY DIFFERENT ARTICLES.

51. The proper temperatures for the refrigerating room depend upon the nature of the article to be preserved. They are about as follows: Fish, meat, and poultry, 20° Fahrenheit; fruit and vegetables, about 35° Fahrenheit.

ICE MAKING.

52. There are now two systems in use for making ice, viz., the **can system** and the **plate system.** The can system is the more common of the two, being cheaper in first cost and requiring less attention in manipulation. The plate system, however, has the advantage of giving a clearer ice.

53. The Can System.—The apparatus used in the can system consists of a large rectangular wood or iron tank

containing the expansion coils or pipes. Galvanized-iron cans are placed between the rows of expansion coils. These cans are filled with distilled water, and when the brine is chilled below the freezing point, the water in the cans freezes. If the temperature of the brine is not allowed to fall below 25° and ordinary well water is used in the cans, the ice produced will be comparatively clear on the outside and rather snowy in the center. If, however, the brine temperature is allowed to fall to about 15°, the ice will be entirely opaque.

54. The Plate System.—In the plate system the refrigerating fluid is circulated through vertical cast or wrought iron hollow plates, set on edge in a tank of water. Ice begins to form on the plate and gradually extends out into the tank. If the temperature of the plate is kept comparatively high at the start until 2 or 3 inches of ice is formed, and then gradually reduced as the ice formation increases, a clear cake or plate of ice will be formed on each side of the plate. The refrigerating fluid is then drained from the plate, and warm water is introduced, which thaws the ice adhering to the sides. As soon as the ice is detached, it floats to the surface of the water in the tank.

BOILERS AND APPLIANCES.

THE BABCOCK-WILCOX BOILER.

55. There is a growing tendency towards the general introduction of water-tube boilers, especially for naval vessels. A type of boiler that seems to have grown into the favor of naval architects of late is the **Babcock-Wilcox water-tube marine boiler,** a description of which is therefore given below, in addition to the types already described.

The boiler shown in Fig. 9 is of the type used in the merchant service. It consists essentially of a series of inclined tubes *a*, *a*, connected to the so-called headers *b*, *b'* at

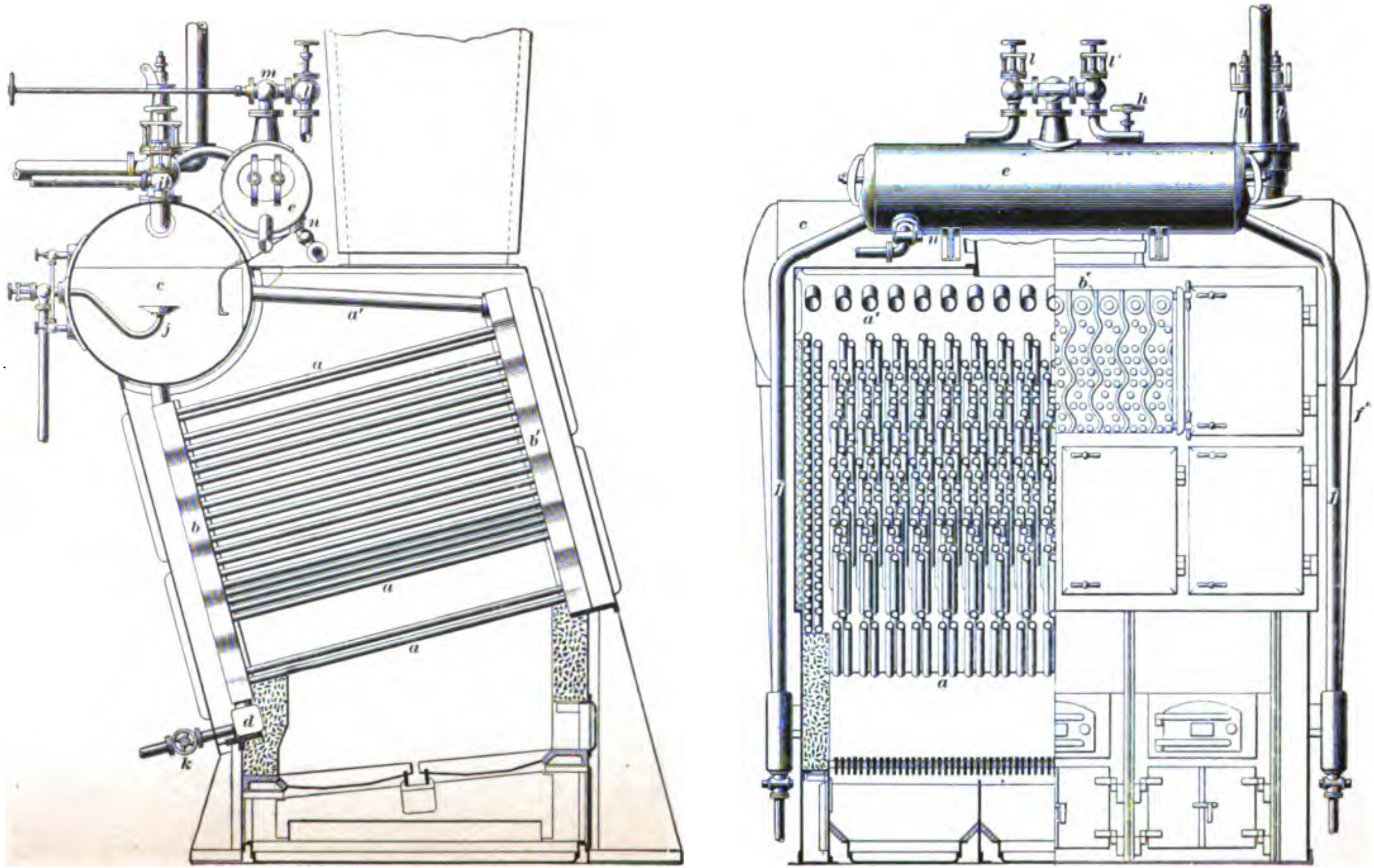


FIG. 9.

the front and rear. The front headers *b'* are connected at the top to a steam drum *c*, which is located at the rear, by a row of horizontal tubes, as *a'*. The rear headers *b* are connected at the top to the bottom of the steam drum and at the bottom to a mud drum *d*. The feed-water enters at the top of the feed-water **purifying drum** *e*, where it is heated to a high temperature by live steam, and thus purified. It then flows by gravity down the down-flow pipes *f*, *f* and enters at both ends of the mud drum. The whole structure, excepting part of the steam drum, the purifying drum, and the down-flow pipes, is surrounded by a wrought-iron casing lined with a non-conducting composition. The furnace proper is built of ordinary firebrick. Numerous suitable doors are provided to allow for cleaning and repairing the boiler. Proper manholes and handholes are fitted to the mud drum, steam drum, and purifying drum. The safety valves *g*, *g*, main stop-valve *h*, and auxiliary stop-valve *i* are fitted to the steam drum. A surface blow-off *j* is also provided. The glass water gauge and gauge-cocks are attached to the steam drum in a suitable location. The bottom blow-off *k* is located in the center of the mud drum. The steam drum is also connected to the mud drum by two down-flow pipes, as *f'*, placed outside of the casing. The main and auxiliary feed check-valves are shown at *l* and *l'*; the feed stop-valve is shown at *m*. At *n* the blow-off of the purifying drum is attached. To allow the inside of the tubes to be readily cleaned, an opening is cut into each header opposite each tube; this opening is closed by a suitable plug.

56. The operation of the boiler is as follows: The boiler being filled with water until the steam drum is half full, the fire is started. The water in the inclined tubes becoming heated first, owing to the tubes being exposed to the most intense heat of the fire, it expands and flows up to the front headers and through the horizontal tubes into the steam drum. Cooler water flows down from the bottom of the steam drum into the rear headers, and also into the mud drum through the outside down-flow pipes. This in turn

becomes heated and flows up the inclined tubes, circulation being thus maintained. The steam bubbles formed in the tubes are liberated in the steam drum, and the steam fills the upper part of the drum. To insure dry steam, a dry-pipe is fitted inside of the steam drum; the main and auxiliary steam pipes take steam through this dry-pipe.

THE PURIFICATION OF FEED-WATER.

57. The impurities contained in the feed-water may be removed or rendered harmless in three ways:

1. By filtration. This method will remove floating impurities, such as oil or grease mixed with the feed-water of a surface condensing engine. It will also quite effectually remove all matter in mechanical suspension, such as earthy matter. Filtration pure and simple will not remove matter in solution.

2. By heat. This method will precipitate carbonate of lime, sulphate of lime, and chloride of sodium, the three scale-forming substances held in solution. The carbonate of lime and the sulphate of lime precipitate as soon as the water is heated to about 290° Fahrenheit. Hence, if the feed-water be heated in a separate vessel to that temperature, the impurities will deposit there instead of in the boiler. Chloride of sodium (salt) will not be precipitated by heating the water unless the water is saturated with it. Chloride of magnesium can not be removed from the water by heating.

3. By chemical means. This method will render harmless the chloride of magnesium contained in solution in sea-water. When water containing chloride of magnesium in a proportion of more than about 200 grains to the gallon is heated to a high temperature, the water will under certain conditions, particularly if corrosion has already set in in the boiler, become acid, and hence highly corrosive. Chemical means will also render harmless fatty acids due to vegetable or animal oils, or adulterated mineral oils having been decomposed by heat.

PURIFYING BY FILTRATION.

58. A **Ross feed-water filter,** designed to remove oil and grease from the feed-water of a surface condensing engine, is shown in Fig. 10. The water coming from the feed-pump enters at *a* and passes into the filtering chamber *b*. It can not leave this filtering chamber without passing through the filter *c*, which consists of light circular bronze sections of open latticework held together by long bolts and covered by toweling. This material is technically known as "linen terry," and popularly as "Turkish toweling." The toweling is made up in the shape of a bag somewhat larger than the spider; it is drawn over it and drawn down between each of the sections by a string wound around it. The feed-water slowly passes through the filtering material into the interior of the filter; it then goes through the left-hand opening of the filtering chamber and through the valve *d* into the feed-pipe again, and thence to the boiler. The foreign matter filtered from the water accumulates on the filtering material, and in course of time offers considerable resistance to the passage of the water. This resistance is shown by the difference in reading of two pressure gauges. One of these is connected to the chamber *b* and the other to the left-hand passage. When this difference amounts to 3 pounds, the filter is in need of cleaning. To clean the filter, close valves *d* and *e* and open the drain at *f*. Now open valve *e* a little. A current of water will then flow around the filter and out of the drain,

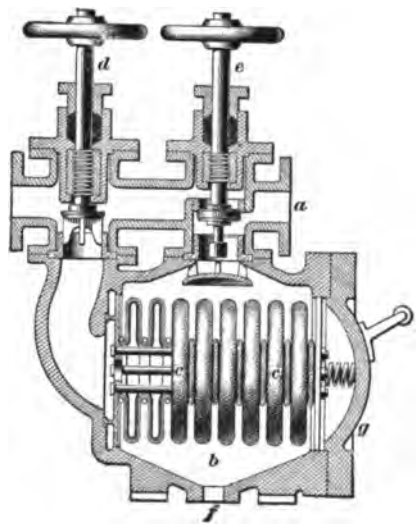


FIG. 10.

washing the outside of the toweling. Next, close valve *e* again and open valve *d*. Then, the drain being open, a current of water will flow through the filter in a direction opposite to that in which the water passes through it when filtering. The water flowing in a reverse direction tends to loosen the foreign matter adhering to the outside of the filter. To start the filter again, open valves *d* and *e* and close the drain. Should it be found that the washing of the filter as explained above is insufficient to clean it, a new filter must be inserted. To do this, close valves *d* and *e* and open the drain. The water from the feed-pump will now pass directly to the boiler, the screwing down of the valve *e* to close the opening to the filter chamber opening a by-pass, as shown. The cover *g* can now be removed and a new filter inserted.

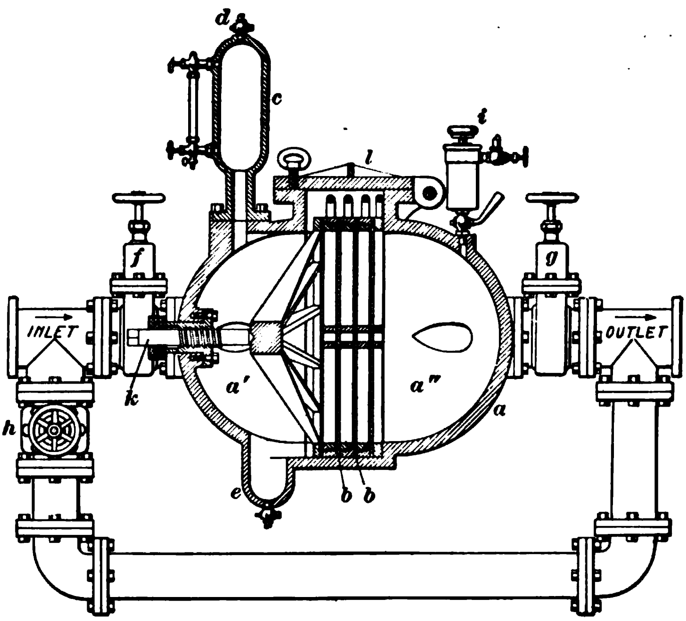


Fig. 11.

59. An **Edmiston feed-water filter** is shown in Fig. 11. It consists of a vessel *a*, divided by perforated plates *b*, *b*, covered with coarse woven cloth, into two

chambers. The feed-water is admitted to the chamber a', and can not reach the chamber a'' except by passing through the filtering cloth. The oil and other floating impurities rise into the scum chamber c, whence they are removed periodically by opening the blow-off d. The heavier impurities settle into the pocket e, which is provided with a blow-off cock. A pressure gauge is attached to the chamber; when this gauge indicates more than five pounds pressure in the chamber in excess of that in the boiler, it shows that the strainer is clogged and must be cleaned. This is done by closing the valves f and g and opening the by-pass valve h, thus cutting the filter out of the feed-pipe. The soda cup i is now filled with soda and steam turned on, thus boiling out the filter. The soda dissolves the grease, and the matter in the filter can then be blown out. If boiling out fails to clear the filter, the filtering diaphragms must be removed and new ones substituted. To do this, first of all cut the filter out of the feed-pipe, letting the feed-water go through the by-pass. Then loosen the set-screw k. Now open the hinged door l. The diaphragms can then be readily removed.

60. The action of these feed-water filters is purely mechanical. By passing the feed-water through the strainers, the foreign matter in suspension or floating on the water is arrested.

PURIFYING BY HEAT.

61. As stated before, heat causes the precipitation of several scale-forming substances. If the water be heated in a separate vessel, and if a large, quiet chamber be provided for the reception of the heated water, a considerable quantity of matter in mechanical suspension will settle at the bottom of the chamber, in addition to the matter precipitated by becoming insoluble.

62. In describing the Babcock-Wilcox boiler, it was mentioned that it has a purifying drum. This is shown in

section in Fig. 12. The cold feed-water enters at the top and is discharged into the pans *a*, *a*. It flows over the edges of these pans, forming a cascade. The water being thus spread out in a large, thin sheet, as it were, readily absorbs the heat of the live steam it comes in direct contact with. The upper part of the drum is filled with live steam coming through *c* from the steam drum. The heated water falls into the settling chamber *d* in the bottom of the drum; flowing over and under the partitions *b*, *b*, it finally enters the down-flow pipes *f*, *f*. The scale-forming substances made insoluble by the heat and precipitated and a good deal of the matter in suspension collect in the settling chamber; they are removed periodically by using the blow-off which connects with the settling chamber. Owing to the view taken, the blow-off can not be seen. The partitions *b*, *b* are removable, thus allowing the drum to be cleaned out readily. This purifier forms part of the boiler itself as furnished by the makers.

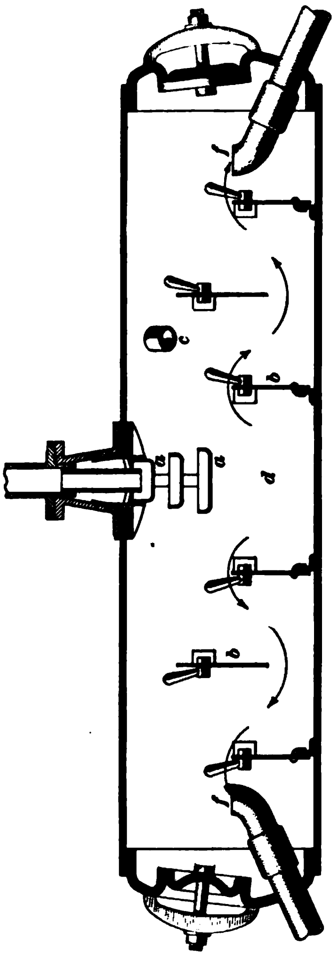


FIG. 12.

63. A **Buffalo feed-water heater and purifier,** which can be applied to any boiler, is shown in Fig. 13. The feed-pumps deliver their water through the pipe *e* and

check-valve *f* into the top of the heater. The entering feed-water strikes against the top division plate; the solid stream of water is thus broken up. It now flows in a zig-zag course over the edges of the spray disks *g*, *g*, being thus spread out into large, thin sheets, which readily absorb the heat of the live steam with which the spray chamber is filled

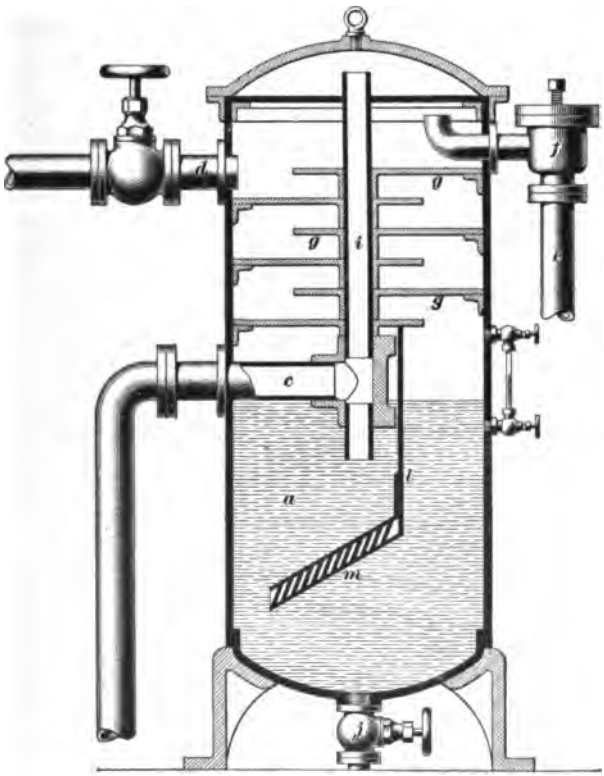


FIG. 13.

and which is admitted through *d*. The highly heated water falls to the bottom, and passing around the division plate *l* and deflector plate *m*, rises up in the settling chamber *a*. Thence it passes through the equalizing tube *i* into the space between the upper division plate and head and into the feed-pipe *c*. The feed-water being heated to almost the

same temperature as that in the boiler, the scale-forming substances precipitate and collect in the bottom of the settling chamber, whence they can be removed by opening the blow-off valve *j*. Nearly all foreign matter in mechanical suspension also collects in this settling chamber, and is removed with the scale-forming substances. The impurities which have a smaller specific gravity than water rise to the top of the settling chamber and float on the water. By extending the equalizing pipe *i*, which forms the feed outlet from the heater, below the surface of the water, the floating impurities are prevented from entering the feed outlet. The heater should be placed above the boilers. The water will then flow into the boilers by gravity. To prevent the water in the boilers from backing up into the heater when the blow-off of the heater is opened, an automatic shut-off valve, which is simply a special form of check-valve, is supplied. This valve is placed in the feed-pipe between the heater and the boilers. Under ordinary working conditions, it is sufficient to blow out the heater once every six hours.

PURIFYING BY CHEMICAL MEANS.

64. Treating Chloride of Magnesium.—When no evaporator is provided for making up the loss of feed-water and the salt feed has to be used instead, the corrosive effect of the chloride of magnesium thus admitted can be neutralized by using the ordinary unslaked lime of commerce. The lime converts the chloride of magnesium into magnesia and chloride of calcium, neither of which is corrosive.

When starting with new boilers, it is recommended that ten pounds of lime should be placed into the boilers for every thousand indicated horsepower on the first day. For the next six days' continuous steaming use about five pounds of lime for every thousand indicated horsepower. When the boilers are examined at the expiration of this time, they should have a thin coating of lime scale all over the inside. If this is not the case, the use of lime should be continued.

Mix the finely powdered lime in the proportion of 1 pound of lime to a gallon of water, thus making the so-called "milk of lime." Introduce it into the hotwell in any convenient manner in small quantities.

It is a good plan to use lime continuously to prevent corrosion. About 1 pound of lime per day for each thousand horsepower is usually sufficient.

65. The use of carbonate of soda for sulphate of lime and grease has been explained in the chapter on Incrustation.

66. It is well to remember that while the foreign ingredients in the feed-water may be rendered harmless by chemical treatment, they are not thus removed from the boiler. The bottom and surface blow-off will hence have to be used periodically to remove as much of the impurities as feasible.

TESTING WATER.

67. Testing for Corrosiveness.—Whenever the density of the water in the boilers is tested, it is a good plan to also test it for corrosiveness. This may be done by placing a small quantity into a glass tumbler and adding a few drops of methyl orange. If the sample of water is acid, and hence corrosive, it will turn pink. If it is alkaline, and hence harmless, it will be yellow. The acidity may also be tested by dipping a strip of blue litmus paper into the water. If it turns red, the water is acid. This method is not as sensitive as the previous one, which should be used in preference. If litmus paper is carried, it should be kept in a bottle with a glass stopper, as exposure to the atmosphere will deteriorate the paper. If the water in the boilers has become corrosive and corrosion has set in, the water in the gauge glass will show red or even black. As soon as the color is beyond a dirty gray or straw color, it is advisable to introduce lime to neutralize the acid.

68. Testing for Carbonate of Lime.—Pour some of the water to be tested into an ordinary tumbler. Add a

little ammonia and ammonium oxalate; then heat to the boiling point. If carbonate of lime is present, a precipitate will be formed.

69. Testing for Sulphate of Lime.—Pour some of the feed-water into a tumbler and add a few drops of hydrochloric acid. Add a small quantity of a solution of barium chloride and slowly heat the mixture. If a white precipitate is formed which will not redissolve when a little nitric acid is added, sulphate of lime is present.

70. Testing for Organic Matter.—Add a few drops of pure sulphuric acid to the sample of water. To this add enough of a pink-colored solution of potassium permanganate to make the whole mixture a faint rose color. If the solution retains its color after standing a few hours, no organic substances are present.

71. Testing for Matter in Mechanical Suspension.—Keep a tumblerful of the feed-water in a quiet place. If no sediment is formed in the bottom of the tumbler after standing for a day, there is no mechanically suspended matter in the water.

CIRCULATING APPARATUS.

72. Of late years much attention has been paid to the improvement of the circulation of the water in marine boilers, and to-day a great many of them are fitted with some apparatus for improving the circulation.

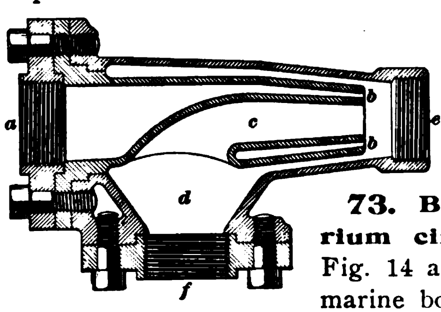


FIG. 14.

73. Bloomsburg's equilibrium circulator is shown in Fig. 14 and its application to a marine boiler in Fig. 15. Referring to Fig. 14, the feed-water enters at *a* in a solid body, and in flowing through the

annular opening *b* assumes a tubular shape. The whole device being immersed in water, the friction of the annular jet issuing at a high velocity from *b* causes the surrounding water to move in the direction of and with the jet, thus inducing a current of water to flow through *f* into *d* and out at *e*.

In Fig. 15 the device is shown applied to a Scotch boiler. In this figure, *a* represents the circulator. The suction pipe *g* is connected to *f* (see Fig. 14). This suction pipe has

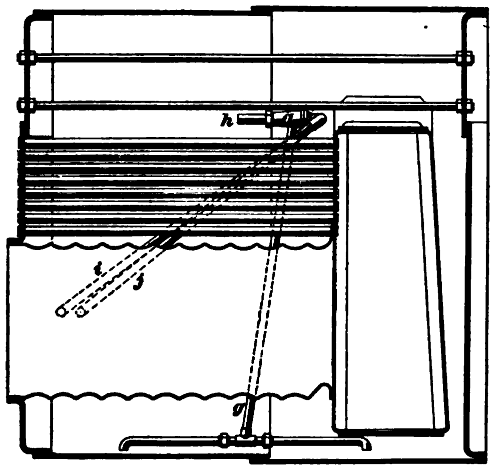


FIG. 15.

two branch suction pipes, taking the water from the coolest part of the boiler. The water is discharged through *h* above the tubes. The main feed-pipe *i* and auxiliary feed-pipe *j* are both connected to the circulator (at *a* in Fig. 14).

74. From the foregoing it is seen that as long as the feed-pumps are working, this device will automatically improve the circulation. In order to improve the circulation while getting up steam, and also in order to heat the water in the boiler, a jet similar to that shown in Fig. 14 is sometimes placed at the junction of the main and branch suction pipes, the jet pointing upwards into the main suction pipe. By means of a suitable pipe connection and

valve, live steam from the donkey boiler or one of the main boilers can then be turned into the jet, thus inducing a current of heated water to flow upwards. By means of this supplementary device, circulation can be kept up and improved when the feed-pumps are not working, or it can be used in conjunction with the circulator if desired.

INDUCED DRAFT.

75. Induced draft by means of a steam jet is to be found in many American steamships, and has much to recommend it. The chief points in favor of the steam jet are the ease with which it can be applied to existing boilers, its low first cost, and the reliability of its action. Besides, being located inside of the smokestack, it does not occupy valuable space. While its steam consumption is greater than that of the fan engine used in mechanical draft installations,

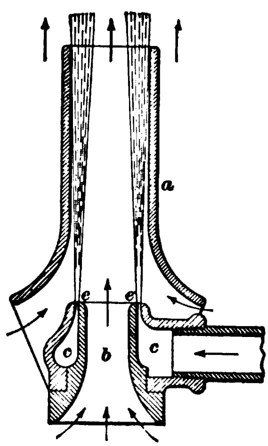


FIG. 16.

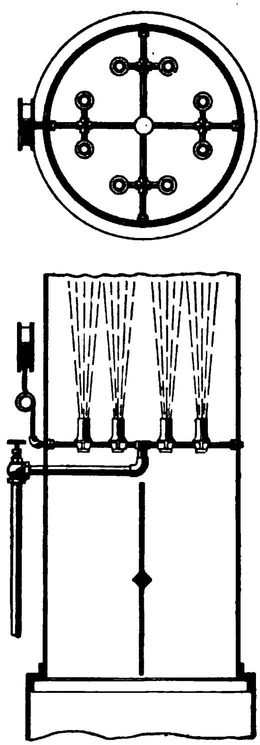


FIG. 17.

it affords a ready means of increasing the evaporative power of a boiler or boiler plant. Whether it will increase

the efficiency of the boiler, that is, the number of pounds of water evaporated per pound of coal, is somewhat doubtful.

In installing a steam jet, it must not be overlooked that the steam used is lost, while with a fan engine the steam can be, and usually is, exhausted into the condenser, thus saving the fresh water. This consideration limits the steam jet chiefly to vessels running in fresh water, and to such other vessels in which the saving of the fresh water is not essential.

76. The construction of a **Bloomsburg steam jet** is shown in Fig. 16. It consists of a casing *a*, having a central nozzle *b* at its lower end. Steam from the boiler enters the chamber *c* formed by the lower part of the casing and the nozzle, and flows through the annular opening at *e*. The steam issuing from this opening at a high velocity, a current of air is induced to flow in the same direction as the steam.

77. A number of these small jets are attached to a spider, which consists of a central casting with radiating steam pipes, the ends of each steam pipe carrying a jet. Its arrangement in the smokestack is shown in Fig. 17. A steam gauge is attached to the system of jets, showing the steam pressure in the jets. To start the induced draft, simply turn the steam on; to regulate the intensity of the draft, open or close the valve.

AUXILIARY MACHINERY.

STEERING ENGINES.

78. Owing to the difficulty of steering large vessels by hand gear, power steering engines were designed and are now almost universally used. Power steering engines may be divided into three different classes:

1. Hydraulic steering engines.
2. Electric steering engines.
3. Steam steering engines.

The first two classes are rarely used, hence only steam steering engines will be considered here.

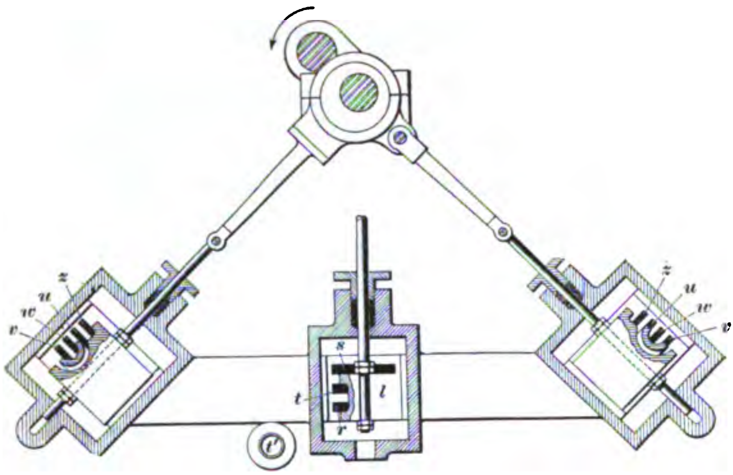
79. Steam steering engines may be again divided into two subclasses:

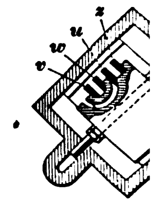
1. Direct connected.
2. Indirect connected.

Direct-connected steam steerers have the piston connected directly either to the tiller or to the tiller ropes. The Cincinnati steam steerer is a representative design belonging to this class.

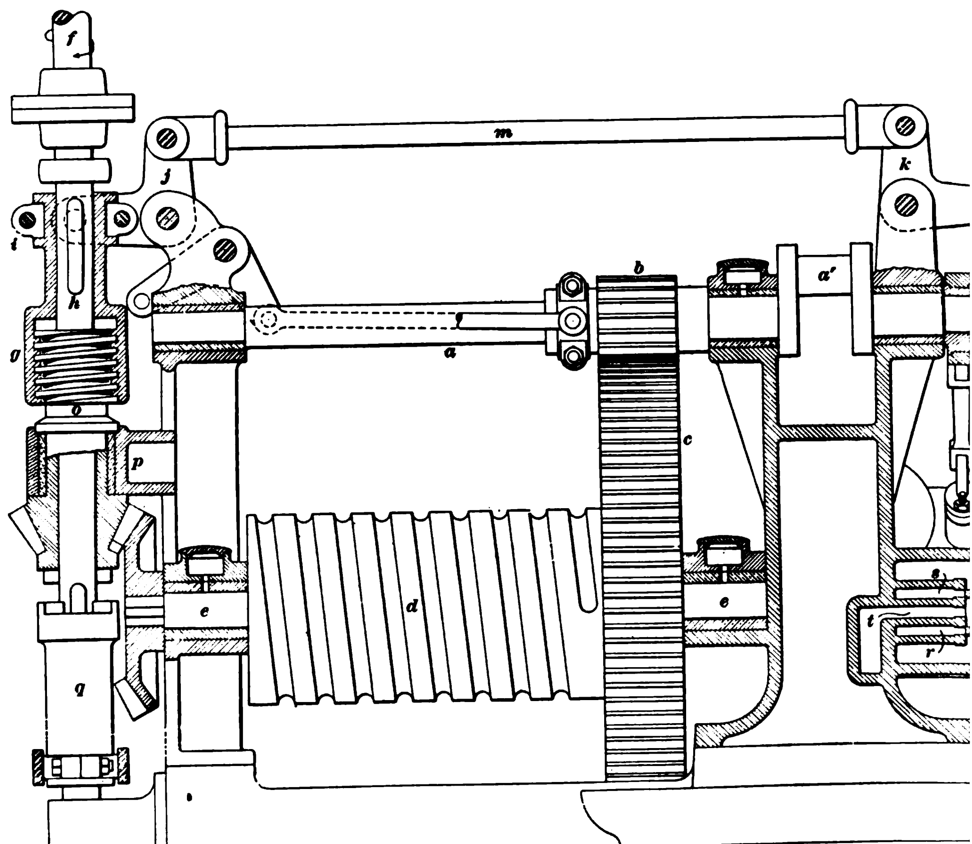
In indirect steam steering engines, the tiller ropes are passed around a drum actuated usually by a pair of steam engines; these steam engines are fitted with a controlling valve and valve gear connected to the steering wheel in the pilot house. The controlling valve and valve gear for both subclasses is constructed in such a manner that the engines or piston will follow the motion of the steering wheel; that is, the engines or piston will be at rest while the wheel is at rest: they will move and actuate the drum or the tiller as soon as the wheel is moved, and they will reverse as soon as the motion of the wheel is reversed.

80. The **Globe steam steering engine** shown in Fig. 18 belongs to the indirect-connected subclass. It consists essentially of two steam engines *A* and *B*, at right angles to each other, and coupled to the crank-pin *a′* of the crank-shaft *a*. The crank-shaft carries a pinion *b*, so mounted that it can be moved along the shaft out of mesh with the gear *c*. The drum *d* and gear *c* are keyed to the drum shaft *e*. Hence, with the pinion and gear in mesh, the engines will actuate the drum, around which the tiller rope is coiled. The object of sliding the pinion along the crank-shaft will be explained farther on. The vertical shaft *f* leads to the pilot house above, and is connected to the steering wheel by bevel gears. An internally threaded sleeve *g* is mounted upon the vertical shaft. This sleeve, while free to slide vertically, is constrained to rotate with the shaft by





(e)



(a)

Fi

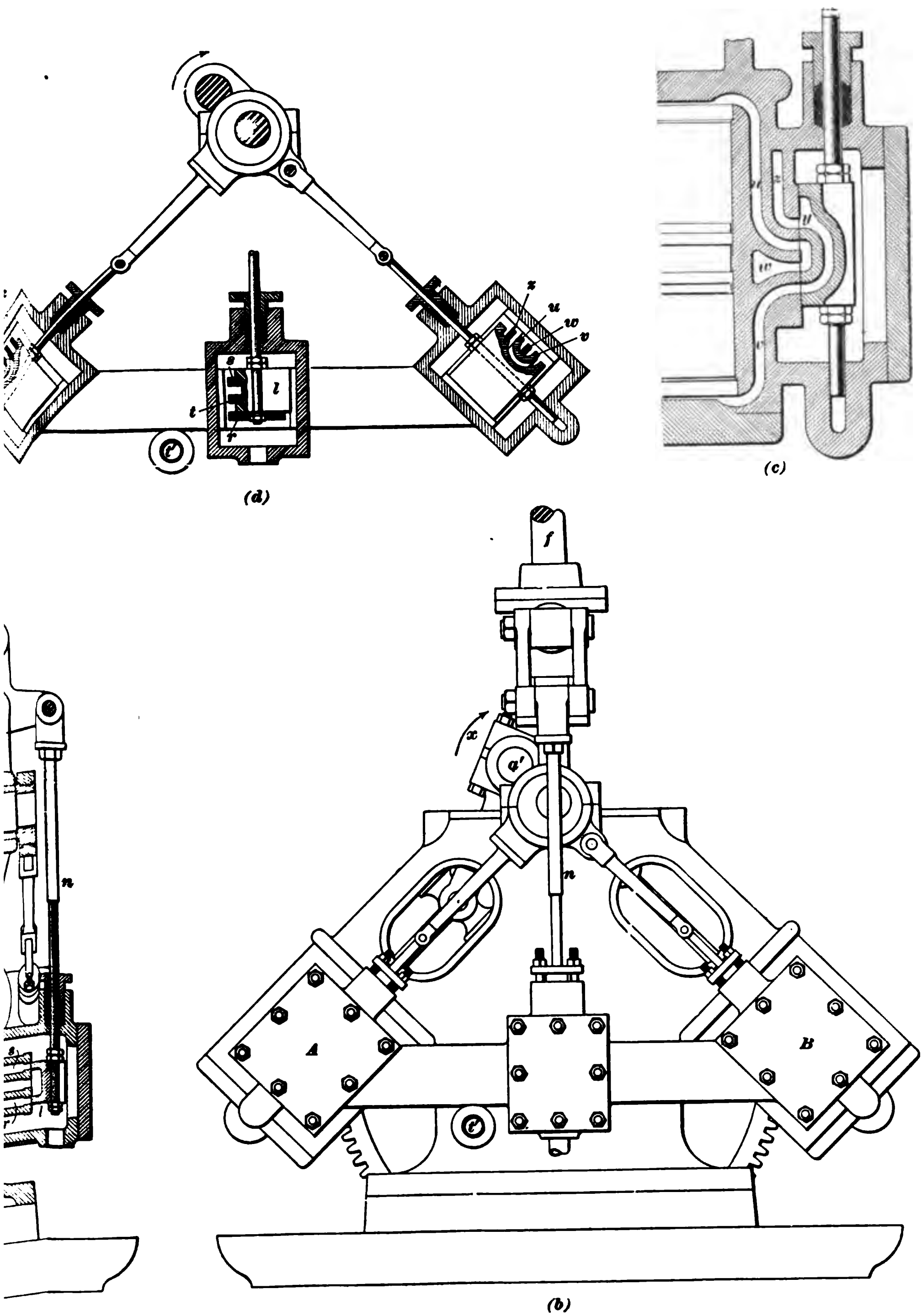


FIG. 18.

a feather *h*. The upper end of the sleeve is surrounded by a yoke *i* carrying studs engaging one end of the bell-crank *j*. Any vertical motion of the sleeve is transmitted to the **change valve** *l* by the bell-cranks *j* and *k*, the rod *m*, and valve stem *n*. The sleeve *g* is screwed over the **hunting screw** *o*, which is loose on the vertical shaft and free to turn in the bearing *p*. The lower end of the hunting screw forms a bevel gear meshing with a larger one keyed to the drum shaft *e*. The hunting screw can be made to rotate with the shaft by sliding the clutch *q* upwards to engage the projections on the lower face of the hunting screw. When steam is used as the motive power, the gears *b* and *c* are in mesh and the clutch *q* is thrown out, thus leaving the hunting screw free to rotate around the vertical shaft.

Let the shaft *f* be turned in the direction of the arrow. Then, the hunting screw being stationary, due to the drum being at rest, the rotation of the vertical shaft causes the sleeve *g* to screw farther over the hunting screw. The sleeve thus moves downwards, causing the change valve *l* to move upwards. This upward movement of the valve uncovers the steam port *r* and places the steam port *s* in communication with the exhaust port *t*. The effect of this is that the engines are started; they now rotate the crankshaft in the direction of the arrow *x*. See Fig. 18 (*b*). As the hunting screw is connected by bevel gears to the drum, the hunting screw is constrained to turn in the *same* direction the shaft *f* was rotated in. The effect of this is to cause the sleeve *g* to move upwards again towards its normal position. This brings the change valve back to mid-position, thus shutting off steam from both cylinders.

When the shaft *f* is turned in a reverse direction, the change valve *l* is moved downwards, thus uncovering the steam port *s*. The engines will now run in an opposite direction, and hence move the drum, and finally the tiller, in a direction opposite to that they moved in when the shaft *f* was turned in the direction of the arrow.

The combination of the bevel gears, hunting screw, sleeve, bell-cranks, connecting-rod, valve stem, and valve here shown

is called a *floating valve gear*, so called because the valve floats back to its original position as soon as the motion of the part originally responsible for the motion of the valve is arrested.

81. In order to show how the change valve *l* reverses the engines, Figs. 18 (*c*), (*d*), and (*e*) have been drawn. Fig. 18 (*c*) is a section through the steam chest of one of the engines, both being alike. Figs. 18 (*d*) and (*e*) are transverse sections taken through the steam chests of both engines and the steam chest of the change valve, showing the change valve in two different positions.

Owing to the fact that the two engines are at right angles to each other and coupled to the same crank, one common eccentric will give a correct motion to the slide valve of each engine. This eccentric is at a right angle to the crank, occupying the position shown in reference to the crank. The valves of the engines have practically no lap, allowing steam to follow nearly full stroke. This insures a ready starting of the engines, no matter what the position of the crank.

Referring now to Fig. 18 (*c*), it will be seen that, in addition to the usual steam passages *u*, *v*, and *w*, there is another steam port *z* which is always in communication with the passage *y* cored in the valve. This port *z* of both cylinders communicates with a passage *s* extending from one cylinder to the other. The passage *w* of both cylinders communicates with a passage *r* extending from one cylinder to the other. There is no communication whatsoever between *r* and *s*, but by means of the cavity in the change valve *l* either *r* or *s* can be put in communication with the exhaust passage *t*, which connects with the exhaust pipe *t'*. The passages *r*, *s*, and *t* are shown in Fig. 18 (*a*). These passages have ports for the change valve; the ports which are clearly shown in views (*d*) and (*e*) are lettered the same as the passages.

82. In Fig. 18 (*d*) is shown the position assumed by the change valve when the vertical shaft *f* is rotated in the

direction of the arrow. Steam now flows into the passage *r* and thence into the passages *w*, *w*. With the crank in the position shown, it is on the dead center for the right-hand engine and on the upper quarter for the left-hand engine. Steam flows from *w* into *v*, and thence to the bottom side of the left-hand piston, causing the crank to rotate in the direction of the arrow. At the same time the upper steam port *u* of the left-hand engine is placed in communication with the passage *z*, and the exhaust steam on the upper side of the piston flows through *u* into *z*, thence into *s* and the exhaust passage *t*, whence it passes out of the exhaust pipe *t'*. As soon as the crank has moved past its center for the right-hand engine, the engine valve moves upwards. Live steam then flows through *r* into *w*, into *u*, and thence to the upper side of the right-hand piston. At the same time the exhaust steam flows from the under side of the right-hand piston through *v* into *z*, into *s*, thence into *t*, and finally into *t'*.

83. Now let the vertical shaft *f* be rotated in a direction opposite to that shown by the arrow, thus causing the change valve *l* to move downwards and open the port *s*. The valve is shown in this position in Fig. 18 (*e*). Live steam now flows through *s* into *z*, into *u*, and thence to the upper side of the piston of the left-hand cylinder. At the same time the exhaust on the lower side of the piston flows through *v* into *w*, into *r*, thence into *t*, and finally into *t'*. Admitting steam to the upper side of the left-hand piston causes the crank to move in the direction of the arrow, that is, in a direction opposite to that it rotated in when the change valve *l* uncovered the port *r* to the live steam. As soon as the crank has moved past its center for the right-hand engine, the valve of that engine moves downwards, thus uncovering the port *u*. Live steam flows through *s* into *z*, thence into *u*, and then to the upper side of the right-hand piston. The exhaust steam on the under side flows at the same time through *v* into *w*, into *r*, into *t*, and finally into *t'*.

It is thus seen that the direction of rotation of the crank-shaft depends entirely upon the position of the change valve, which is the controlling valve previously mentioned.

84. The steering engine here shown is adapted to be worked by hand power, if necessary. The gear *b*—see Fig. 18 (*a*)—is slid along the shaft out of mesh with *c*, thus disconnecting the engines from the steering drum. The clutch is then raised to engage the projections on the lower face of the hunting screw, thus forcing the hunting screw to rotate together with the sleeve. Then, by turning the shaft *f*, the bevel gears actuate the steering drum. To change back to steam power, drop the clutch *q* and slide the gear *b* into mesh again.

REVERSING GEARS.

85. Nearly all the larger marine engines are fitted with power reversing gear, usually steam gear. Hydraulic reversing gears are fitted to some engines, but as these are only very few in number, they will not be treated here.

86. Steam reversing gears may be divided into two general classes:

1. **Indirect Reversing Gears.**—In these a quadrant of a worm-wheel is keyed to the rocker-arm shaft. A worm meshing with the quadrant is fastened to the crank-shaft of a small engine, which, by rotating the worm, operates the rocker-shaft, and hence the links. Steam reversing gears of this type are not only slow in operation, but also, in the larger sizes, require for their operation one or even two men in addition to the engineer standing at the throttle. While in common use in European steamers, they have not found much favor in American vessels.

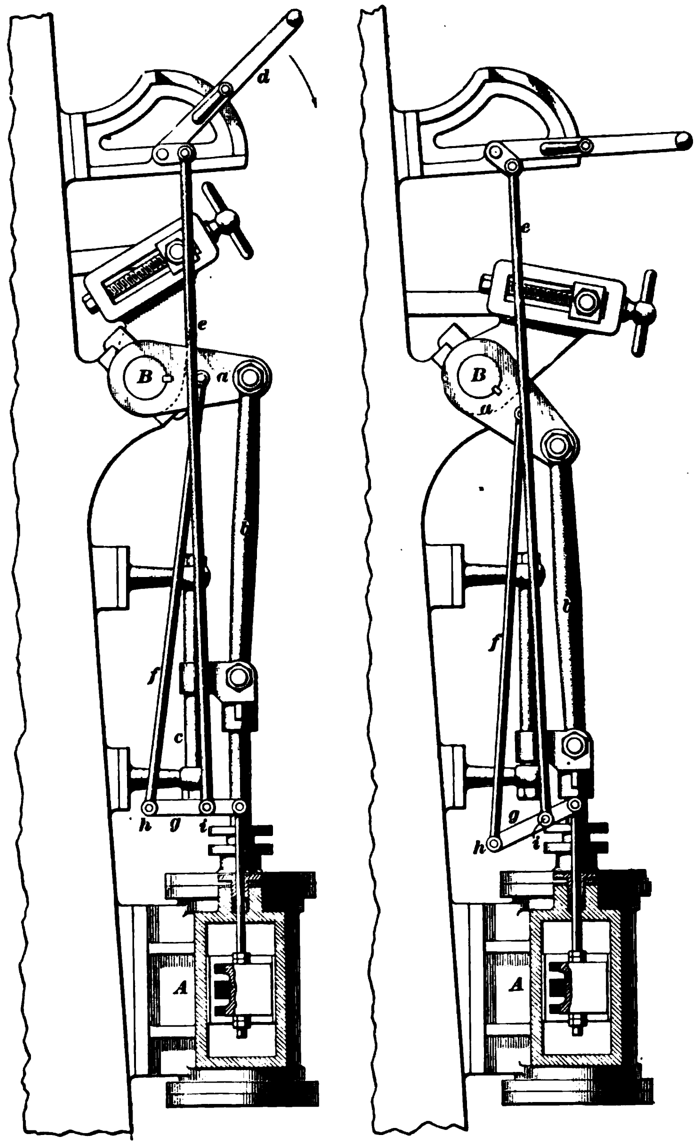
2. **Direct Reversing Gears.**—In this class of gear, the piston in a steam cylinder is attached directly to a crank arm on the rocker-shaft by a piston rod and connecting-rod. A small reversing lever, placed alongside of the throttle lever, operates a peculiar valve gear and valve, causing the

piston to assume a position corresponding directly to the position of the reverse lever. This type of gear is often called a **steam ram,** and is the type in common use in American vessels. With it one man can handle the largest engine with little exertion.

87. The construction of a steam ram of approved design is shown in Fig. 19. The steam cylinder *A* is fitted with a piston, which is connected to the crank arm *a* on the rocker-shaft by the rod *b*. The cross-head is guided by the guide *c* carried in brackets bolted to the column. These brackets form stops at the same time, and determine the "hard over" positions of the link. An ordinary **D** slide valve having only a small amount of lap is fitted to the ram cylinder. The slide valve is connected to the reverse lever *d* by the rods *e* and *f* and the lever *g*. The combination of the reverse lever with the rods *e* and *f*, the lever *g*, and the valve forms a floating valve gear.

In Fig. 19 (*a*) the reversing gear is shown in the position occupied when the link is in mid-gear. Let the reverse lever be moved in the direction of the arrow. Then, the crank arm *a* being at rest, the rod *e* will cause the lever *g* to turn about *h* as a fulcrum. Consequently the valve will move downwards and open the upper steam port, thus admitting steam to the upper side of the piston. At the same time the lower steam port is put in communication with the exhaust port. Steam being turned on, the piston descends. But as the rod *f* is connected to the crank arm *a*, the movement of the crank arm causes the fulcrum *h* to move downwards, and thus causes the lever *g* to turn about the fulcrum *i*, which in turn moves the valve in a direction *opposite* to that in which it was moved by the reverse lever.

This closes the upper steam port a moment after the reverse lever is stopped. If the reverse lever is kept in motion, the steam port will remain open as long as the lever moves. To get the engine to run in an opposite direction, the reverse lever is moved in a direction opposite to that shown by the arrow.



(a) (b)

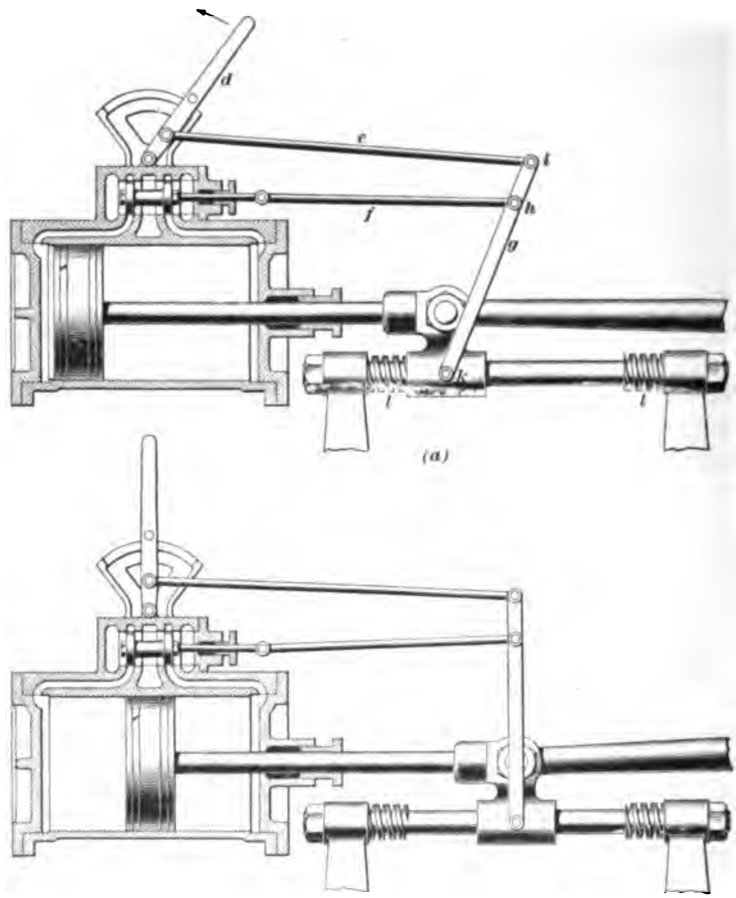
FIG. 19.

In Fig. 19 (*b*) the reversing gear is shown in the position occupied when the piston is at the lowest part of the stroke. It is seen that although the levers and rods of the floating gear occupy an entirely different relative position from that shown in Fig. 19 (*a*), the valve is yet in its mid-position. The valve will always be central over the ports when steam is turned on and the reverse lever at rest.

88. It may be asked, how is the reversing gear prevented from creeping, that is, changing its position under the jarring due to the running of the engine? With the links in full gear, the parts of the reversing gear are in the position shown in Fig. 19 (*b*). Now, suppose that, due to steam leaking past the valve and due to vibration, the piston commenced to creep upwards. The rod *e* being stationary, any upward rotation of the crank arm *a* will immediately cause the lever *g* to rotate around the fulcrum *i*, thus admitting live steam to the upper side of the piston and returning it at once to its former position. Sometimes the cross-head is provided with a clamping screw, by means of which it may be clamped to the guide. If such a clamping arrangement is provided to prevent creeping, it is not necessary to keep steam turned on the cylinder.

89. A somewhat different form of a floating valve gear as applied to a steam reversing gear is shown in Fig. 20. Instead of a **D** slide valve, an indirect piston valve, which takes steam at the inside and exhausts on the outside, is employed. The reverse lever *d* is attached by the rod *e* to the lever *g*, which is fulcrumed at *k* to the cross-head. With the piston at the end of the stroke, as shown in Fig. 20 (*a*), the links are in full gear. Now let the reverse lever be moved in the direction of the arrow. This movement will cause the lever *g* to rotate about the fulcrum *k* in the same direction as the reverse lever. The rod *f* being attached to the valve stem, and to the lever *g* at *h*, the valve is pushed to the left; being an indirect valve, it admits steam to the left-hand side of the piston, opening the right-hand side to the exhaust at the

same time. As the piston moves to the right, the lever *g* now turns about *i* as a fulcrum, and hence the rod *f* moves to the right, the valve thus returning to its central position.



(b)

FIG. 20.

As long as the reverse lever is kept in motion, the steam port will be kept open, and hence the piston will move, but as soon as the reverse lever is stopped, the onward movement of the piston will automatically close the steam port, which in turn stops the piston. In Fig. 20 (*b*) the reversing

gear is shown in the position occupied when the links are in mid-gear. The valve is seen to be in its central position. To prevent shocks occasioned by a too rapid movement of the reverse lever, buffer springs *l*, *l* are sometimes fitted.

Should the piston creep, the movement of the lever *g*, incidental to the motion of the piston, will open the steam port and automatically return the piston to its original position. Suitable stops prevent the valve from traveling farther than is required to open the steam ports to their full extent.

90. When using a steam reversing gear, move the reverse lever with a slow, steady motion. The piston will then follow the lever, and can be brought to rest almost at any desired point. If the lever be moved suddenly, the piston will also move suddenly, and the momentum of the heavy moving parts will carry them beyond the point at which it is intended to stop them. A violent blow can thus be struck to the brackets, which may be heavy enough to carry them away. Likewise, a jerky motion of the reverse lever will produce a jerky motion of the piston and prevent its being stopped exactly where wanted.

Before moving the links, it is advisable to see that everybody is clear of the links. A little forethought in this direction may prevent serious injury to a fellow employee.

DYNAMOS AND MOTORS.

(PART 1.)

INTRODUCTION.

1. Electricity is the name given to the cause of all electrical phenomena. The word is derived from a Greek word meaning *amber*, that substance having been observed by the Greeks to possess peculiar properties which we now understand to be due to electricity.

Although electrical science has advanced sufficiently far to recognize the fact that the exact nature of electricity is unknown, yet recent research tends to demonstrate that all electrical phenomena are due to a peculiar strain or stress of a medium called *ether;* that when in this condition the *ether* possesses *potential energy* or *capacity for doing work*, as is manifested by attractions and repulsions, by chemical decomposition, and by luminous, heating, and various other effects.

In all probability, electricity is not a form of matter, for it possesses only two physical properties in common with material substances, namely, **indestructibility** and **elasticity**; it does not possess *weight*, *extension*, or any of the other physical properties of matter.

Electrical science is founded upon the effects produced by the action of certain forces upon matter, and all knowledge of the science is deduced from these effects. The study of the fundamental principles of electricity is an analysis of a series of experiments, and the classification of the results in each particular case under general laws and rules. It is not necessary to keep in mind any hypothesis of the exact nature of electricity; its effects and the laws which govern them

are quite similar to those of well-known mechanical and natural phenomena, and will be best understood by comparison. The two most essential features, therefore, in acquiring a knowledge of the electrical science, are: first, to learn how to develop electrical action; and, second, to determine the effects produced by it.

2. The number of processes for developing electrical action is almost innumerable, but the most important can be classified under one of the following general heads:

(*a*) By the contact of dissimilar substances;
(*b*) By chemical action;
(*c*) By the application of heat;
(*d*) By magnetic induction.

3. The presence of electricity, also, can be detected in many different ways; under certain conditions, it will

(*a*) Cause attractions and repulsions of light particles of matter, such as feathers, pith, gold-leaf, pieces of paper, etc.

(*b*) Decompose certain forms of matter into their various elements and cause other chemical changes.

(*c*) Produce motion in a freely suspended magnetic needle, such as the needle of a compass.

(*d*) Violently agitate the nervous system of all animals, causing a **shock.**

(*e*) Heat the substances through which it acts.

These are the principal effects produced by the action of electricity; others of less importance will appear from time to time during the study of the different branches of the science.

4. Electricity may either appear to reside upon the surface of bodies as a **charge,** under *high pressure* or *tension*, or flow through their substance as a **current,** under comparatively *low pressure* or *tension.*

That branch of the science which treats of charges upon the surface of bodies is termed **electrostatics,** and the charges are said to be **static charges** of electricity.

Electrodynamics is that branch which treats of the action of *electric currents.*

STATIC CHARGES.

5. When a glass rod or a piece of amber is rubbed with silk or fur, the parts rubbed will have the property of attracting light particles of matter, such as pieces of silk, wool, feathers, gold-leaf, pith, etc., which, after momentary contact, are repelled. These attractions and repulsions are caused by a static charge of electricity residing upon the surface of those bodies. A body in this condition is said to be **electrified.**

A better experiment for demonstrating this action is to suspend a small pith-ball by a silk thread from a support or bracket, as shown in Fig. 1. If a *static charge* of electricity be developed on a *glass rod*, by rubbing it with *silk*, and the rod be brought near the pith-ball, the ball will be attracted to the rod, but, after momentary contact, will be repelled. By this contact the ball receives a charge of the same nature as that on the glass rod, and as long as the two bodies retain their charges, mutual repulsion will take place whenever they are brought near each other. If a stick of *sealing-wax*, electrified by being rubbed with fur, is approached to another pith-ball, the same results will be produced, i. e., the ball will fly towards the sealing-wax, and after contact will be repelled. But the charges respectively developed in these two cases are not in the same condition. For, if, after the pith-ball in the first case had been touched with the *glass rod* and repelled, the electrified *sealing-wax* be brought in the vicinity, *attraction* would take place between the ball and the sealing-wax. Conversely, if the pith-ball be charged with the electrified sealing-wax, it will be repelled by the wax and attracted by the glass rod.

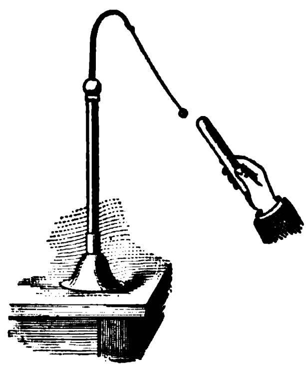


FIG. 1.

An electric charge developed upon *glass* by rubbing it

with silk has been termed, for convenience, a **positive** (+) **charge,** and that developed on resinous bodies, by rubbing with flannel or fur, a **negative** (—) **charge.**

Neither a positive nor a negative charge is produced alone, for there is always an equal quantity of both charges produced; one charge appearing on the body rubbed, and an equal amount of the opposite charge upon the rubber.

The intensity of the charge developed by rubbing the two substances together is independent of the actual amount of friction which takes place between the bodies. For, in order to obtain the highest possible degree of electrification, it is only necessary to bring every portion of one surface into intimate contact with every particle or every portion of the other; when this is done, no extra amount of rubbing can develop any greater charge upon either substance.

6. From the foregoing experiments are derived the following laws:

When two dissimilar substances are placed in contact, one of them always assumes the positive and the other the negative condition, although the amount may sometimes be so small as to render its detection very difficult.

Electrified bodies with similar charges are mutually repellent, while electrified bodies with dissimilar charges are mutually attractive.

7. In the following list, called the **electric series,** the substances are arranged in such order that each receives a *positive* charge when rubbed or placed in contact with any of the bodies following it, and a *negative* charge when rubbed with any of those which precede it:

1. Fur.	6. Cotton.	11. Sealing-wax.
2. Flannel.	7. Silk.	12. Resins.
3. Ivory.	8. The body.	13. Sulphur.
4. Crystals.	9. Wood.	14. Gutta-percha.
5. Glass.	10. Metals.	15. Gun-cotton.

For example, *glass* when rubbed with *fur* receives a *negative* charge, but when rubbed with *silk* it receives a *positive* charge.

CONDUCTORS AND NON-CONDUCTORS.

8. Only that part of a dry glass rod which has been rubbed will be electrified; the other parts will produce neither repulsion nor attraction when brought near a suspended pith-ball. The same is true of a piece of sealing-wax or resin. These bodies do not readily *conduct* electricity; that is, they *oppose* or *resist* the passage of electricity through them. Therefore, it can only reside as a *charge* upon that part of their surface where it is developed. Experiments show that when a metal receives a charge at any point, the electricity immediately passes or flows through its substance to all parts. Metals, therefore, are said to be **good conductors** of electricity. Bodies have accordingly been divided into two classes, i. e., **non-conductors,** or **insulators,** or those bodies which offer a very high **resistance** to the passage of electricity, and **conductors,** or those bodies which offer a comparatively low resistance to its passage. This distinction is not absolute, for all bodies conduct electricity to some extent, while there is no known substance which does not offer some resistance to the flow of electricity.

In giving the following list and dividing the different substances into two classes, it should be understood that it is done only as a guide for the student. Between these two classes are many substances which might be included in either list, and no hard or fast line can be drawn.

Silver, Copper, Other Metals, Charcoal, Ordinary Water, The Body.	CONDUCTORS.
Paper, Oils, Porcelain, Wood.	NON-CONDUCTORS OR INSULATORS.

Silk, Resins, Gutta-percha, Shellac, Ebonite, Paraffin, Glass, Dry Air, etc.	NON-CONDUCTORS OR INSULATORS.

ELECTRODYNAMICS.

9. In dealing with *electric currents*, the word **potential** will be substituted for the general and vague phrase *electrical condition.*

The term *potential*, as used in electrical science, is analogous with *pressure*, in gases; *head*, in liquids; and *temperature*, in heat.

When an electrified body, *positively* charged, is connected to the earth by a conductor, electricity is said to flow *from* the body *to* the earth; and, conversely, when an electrified body, *negatively* charged, is connected to the earth in a similar manner, electricity is said to flow *from* the earth *to* that body. This is called the **direction of flow** of an electric current. That which determines the *direction of flow* is the relative *electrical potential* or *pressure* of the two charges in regard to the earth.

It is impossible to say with certainty in which direction electricity really flows, or, in other words, to declare which of two points has the higher and which the lower electrical potential, or pressure. All that can be said with certainty is that when there is a *difference of electrical potential*, or *pressure*, electricity tends to flow *from* the point of higher *to* that of the lower *potential* or *pressure.*

For convenience, it has been arbitrarily assumed and conventionally adopted that that electrical condition called *positive* is at a higher potential or pressure than that called *negative*, and that electricity tends to flow *from* a *positively to* a *negatively* electrified body.

The zero or normal level of water is taken as that of the surface of the sea, and the normal pressure of air and gases as that of the atmosphere at the sea-level; similarly, there is a *zero potential*, or *pressure, of electricity* in the earth itself. The earth may be regarded as a reservoir of electricity of infinite quantity, and its potential, or pressure, may therefore be taken as zero.

The electrical condition called *positive* is assumed to be at a higher potential or pressure than the earth, and that called *negative* is assumed to be at a lower potential or pressure than the earth.

10. It must be understood that electricity is a *condition of matter*, and not matter itself, for it possesses neither *weight* nor *dimensions*. Consequently, the statement that electricity is *flowing* through a conductor must not be taken too literally; it must not be supposed that any material substance, such as a liquid, is actually passing through the conductor in the same sense as water flows through a pipe. The statement that electricity is flowing through a conductor is only another way of expressing the fact that the conductor and the space surrounding it are in different conditions than usual and that they possess unusual properties. The action of electricity, however, is quite similar in many respects to the flow of liquids, and the study of electric currents is much simplified by the analogy.

11. In order to produce what is called an electric current, *it is first necessary to cause a difference of electrical potential between two bodies or between two parts of the same body.*

It was stated that when two dissimilar substances are simply placed in contact, one always assumes the positive and the other the negative condition; or, in other words, *a difference of electrical potential is developed between the two bodies.*

Placing a piece of copper and zinc in contact will develop a difference of electrical potential which can easily be detected. The same results will follow if the plates are

slightly separated from each other and placed in a vessel containing saline or acidulated water, leaving a small portion of one end of each plate exposed. The exposed ends of the zinc and copper are now electrified to different degrees, or, in other words, there is a *difference of electrical potential* between them, one plate being at a higher potential than the other.

When the exposed ends are connected by any conducting material, the potential between the plates tends to *equalize* and a momentary rush or discharge of electricity passes between the exposed ends through the conductor, and also between the submerged ends through the liquid. During its passage through the liquid, the electricity causes certain chemical changes to take place; these chemical changes cause in their turn a fresh *difference of potential* between the plates, which is followed immediately by another equalizing discharge, and that by a further difference, and so on. These changes follow one another with great rapidity—so rapid, in fact, that it is impossible to distinguish them apart, and they appear absolutely *continuous*. The equalizing flow which is constantly taking place from one plate to the other is known as a **continuous current** of electricity. Consequently, an electric current becomes continuous when the difference of potential is constantly maintained.

By the use of a very delicate instrument, the submerged end of the copper is found to be electrified with a *negative* charge, while the submerged end of the zinc is electrified with a *positive* charge. The direction of the current, therefore, will be *from* the *submerged* end of the zinc through the liquid *to* the *submerged* end of the copper, and *from* the *exposed* end of the copper *to* the *exposed* end of the zinc.

12. A **simple voltaic,** or **galvanic, cell,** Fig. 2, is an apparatus for developing a continuous current of electricity. It consists essentially of a vessel containing saline or acidulated water in which are submerged two plates of dissimilar metals, or one metal and a metalloid (as, for instance, carbon).

Electrolyte is the name given to the liquid, which, as it transmits the current, is decomposed by it.

The two dissimilar metals, when spoken of separately, are called **voltaic,** or **galvanic, elements;** and, when taken collectively, are known as a **voltaic couple.**

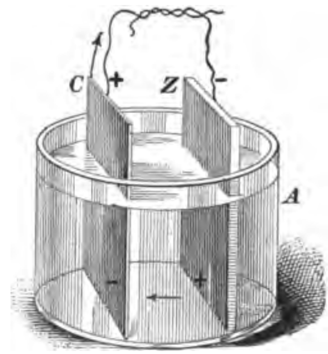


FIG. 2.

A **voltaic,** or **galvanic, battery** is a number of simple cells properly joined together.

Electrodes, or **poles,** of a cell or battery are metallic terminals or connectors attached to the exposed ends of the plates, and are used to connect the cell or battery to any exterior conductor or to another cell or battery.

It should be remembered that the polarity of the submerged ends of the plates is always of opposite sign to that of their electrodes. For example, in the case of the zinc and copper couple, the electrode fastened to the zinc would be spoken of as the *negative* electrode of the cell, while the zinc itself would be the *positive* element of the cell, its submerged end being *positive.*

In any voltaic, or galvanic, couple, the element which is acted upon by the electrolyte will always be the *positive* element, and its electrode the *negative* electrode of the cell.

13. The following list of voltaic elements composes what is called the **electromotive series:**

1. Zinc.	5. Iron.	9. Copper.
2. Cadmium.	6. Nickel.	10. Silver.
3. Tin.	7. Bismuth.	11. Gold.
4. Lead.	8. Antimony.	12. Platinum.
	13. Graphite.	

Any two of these metals form a *voltaic couple* and produce a difference of potential when submerged in saline or

acidulated water, the one standing first on the list being the *positive* element or plate, and the other the *negative*. For example, if *nickel* and *graphite* are used, the *nickel* will be acted upon by the liquid and will form the *positive* element; but if *nickel* and *zinc* are used, the *zinc* will be acted upon by the liquid, and hence will be the *positive* element.

The difference of potential will be greater in proportion to the distance between the positions of the two substances in the list. For example, the difference of potential developed between *zinc* and *graphite* is much greater than that developed between *zinc* and *nickel;* in fact, the difference of potential developed between zinc and graphite is equal to the difference of potential developed between zinc and nickel *plus* that developed between nickel and graphite.

Electricity flowing as a *current* differs from *static charges* in three important degrees—namely, (1) its *potential* is much lower, (2) its *actual quantity* is greater, and (3) it is *continuous.*

A substance charged from a strong voltaic battery possesses the property of attracting light substances only in the slightest degree; in fact, the attractions can only be detected with the most delicate instruments. The *potential* of a current of electricity is comparatively so small that a voltaic battery composed of a large number of cells is not sufficient to produce a spark more than one or two hundredths of an inch long in air, whereas a small, rapidly moving leather belt will sometimes produce static sparks of more than an inch in length. The length of the spark affords a means of estimating potentials, a high potential being capable of producing a longer spark than a low potential, but the length of spark gives us no means of estimating the **current strength** or quantity of electricity flowing. The actual *quantity* of electricity is measured by the amount of water it will decompose. Gauged by this standard, the quantity of electricity produced by a voltaic cell no larger than a thimble would be found greater than that from a large, rapidly moving belt, giving static sparks several inches in length.

14. There are three different methods of connecting or grouping the cells in a voltaic battery: *In series; in parallel, or multiple-arc; in multiple-series.*

Cells are connected **in series** when the positive electrode of the first cell is connected to the negative electrode of the second, and the positive electrode of the second is connected to the negative electrode of the third, and so on, as shown in the diagram, Fig. 3. In this we have adopted the usual signs for representing a cell, the short, broad line representing the positive electrode of the cell and the long, narrow line the negative electrode. In this method of connecting or grouping of cells, when the negative electrode of the first cell is connected to the positive electrode of the last by some exterior conductor, the total current produced will flow successively through each cell. This method of grouping is used when there is available a large number of *low* potential cells and a *high* potential is desired, as in long telegraph-lines or any other *high* resistance circuit.

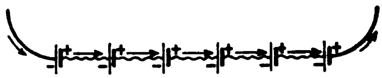


FIG. 3.

15. Cells are connected in **parallel,** or **multiple-arc,** when the positive electrodes of all the cells are connected to one main positive conductor and all the negative electrodes are connected to one main negative conductor, as shown by the diagram, Fig. 4. In parallel, or multiple-arc, grouping, only a part of the total current flowing in main conductors will pass through each cell. This method of grouping is used when it is desired to obtain a strong current from a number of cells (when the external resistance is *low*), as in electroplating.

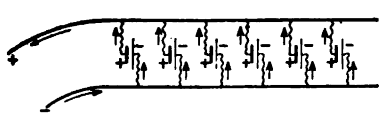


FIG. 4.

16. Cells are connected in **multiple-series** by arranging them in several groups, each group being composed

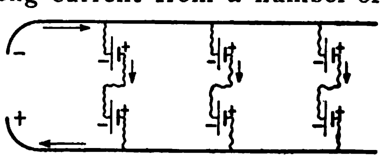


FIG. 5.

of several cells connected in series, and then connecting all the groups together in parallel, or multiple-arc, as shown in the diagram, Fig. 5. This method is used where both a higher potential and a stronger current are required than any one cell of the group will give.

CIRCUITS.

17. A **circuit** is a path composed of a conductor, or of several conductors joined together, through which an electric current flows from a given point around the conducting path back again to its starting-point.

A circuit is **broken,** or **open,** when its conducting elements are disconnected in such manner as to prevent the current from flowing.

A circuit is **closed,** or **complete,** when its conducting elements are so connected as to allow the current to flow.

A circuit in which the earth, or ground, forms part of the conducting path is called an **earth,** or a **grounded,** circuit.

The **external** circuit is that part of a circuit which is outside or external to the electric source.

The **internal** circuit is that part of a circuit which is included within the electric source.

In the case of the simple voltaic cell, the *internal circuit* consists of the two metallic plates, or elements, and the electrolyte; an *external circuit* would be a wire or any conductor connecting the free ends of the electrodes.

18. Conductors are said to be connected **in series** when they are so joined together as to allow the current to pass consecutively through each. For example, Fig. 6 represents a *closed* circuit consisting of a simple voltaic cell B and four conductors a, b, c, and d, connected *in series.*

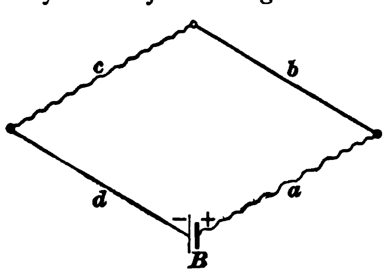


FIG. 6.

A circuit which is divided into two or more branches,

each branch transmitting part of the main current, is a **derived,** or **shunt, circuit,** and the separate branches are said to be connected in **parallel,** or **multiple-arc.** An example of a *derived* circuit of two branches in *parallel* is shown in Fig. 7. The main current flows first through the conductor *a*, then divides between the branches *c* and *b*, and finally uniting and completing the circuit through the conductor *d*; the two branches *c* and *b* being the conductors, which are connected in *parallel*, or *multiple-arc.* The way the current divides, and how the amount which will flow through the branches *b* and *c* is determined, will be treated of later.

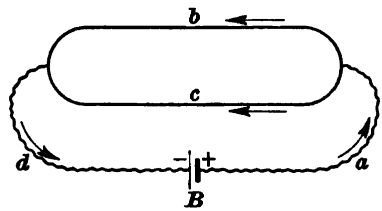


FIG. 7.

MAGNETISM.

19. Magnets are substances which have the property of attracting pieces of iron or steel, and the term **magnetism** is applied to the cause of this attraction. *Magnetism* exists in a natural state in an ore of iron, which is known in chemistry as *magnetic oxide of iron*, or *magnetite.* This magnetic ore was first found by the ancients in *Magnesia*, a city in Asia Minor; hence, substances possessing this property have been called magnets.

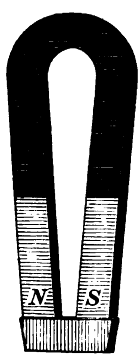


FIG. 8.

It was also discovered that when a small bar of this ore is suspended in a horizontal position by a thread, it has the property of pointing in a north and south direction. From this fact the name **lodestone**—*leading-stone*—was given to the ore.

When a bar or needle of hardened steel is rubbed with a piece of lodestone, it acquires magnetic properties similar to those of the lodestone, without the latter losing any of its own force. Such bars are called **artificial** magnets.

Artificial magnets which retain their magnetism for a long time are called **permanent magnets.**

The common form of artificial, or permanent, magnet, Fig. 8, is a bar of steel bent into the shape of a *horseshoe* and then hardened and magnetized. A piece of soft iron, called an **armature,** or a **keeper,** is placed across the two free ends, which helps to prevent the steel from losing its magnetism.

20. If a bar magnet is dipped into iron filings, the filings are attracted towards the two ends and adhere there in tufts, while towards the center of the bar, half way between the two ends, there is no such tendency. (See Fig. 9.) That part of the magnet where there is no appar-

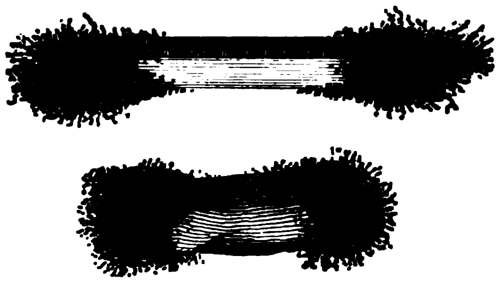


FIG. 9.

ent magnetic attraction is called the **neutral line,** and the parts around the two ends where the attraction is greatest are called **poles.** An imaginary line drawn through the center of the magnet, from end to end, connecting the two poles together, is called the **axis of magnetism.**

A **compass** consists of a magnetized steel needle, Fig. 10, resting upon a fine point, so as to turn freely in a horizontal plane. When not in the vicinity of other magnets or magnetized iron, the needle will always come to rest with one end pointing towards the north and the other towards the south. The end pointing northward is the **north-seeking pole,** or, simply, the *north pole*, and the opposite end is the **south-**

FIG. 10.

seeking or *south pole.* This *polarity* applies as well to all magnets.

If the *north pole* of one magnet is brought near the *south pole* of another magnet, attraction takes place; but if two north poles or two south poles are brought together, they repel each other. In general, *like magnetic poles repel one another; unlike poles attract one another.*

The earth is a great magnet whose magnetic poles coincide nearly, but not quite, with the true geographical north and south poles. A freely suspended magnet, therefore, will always point in an approximately north and south direction.

It is impossible to produce a magnet with only one pole. If a long bar magnet is broken into any number of parts, each part will still be a magnet and have two poles, a north and a south one.

21. Magnetic substances are those substances which, although not in themselves magnets, that is, not possessing poles and neutral lines, are, nevertheless, capable of being attracted by a magnet. In addition to iron and its alloys, the following elements are magnetic substances: *Nickel, cobalt, manganese, oxygen, cerium,* and *chromium.* These, however, possess magnetic properties in a very inferior degree compared with iron and its alloys. All other known substances are called **non-magnetic substances.**

22. The space surrounding a magnet, in which any magnetic substance will be attracted or repelled, is called its **magnetic field,** or, simply, its **field.** Magnetic attractions and repulsions are assumed to act in a definite direction and along imaginary lines called **lines of magnetic force,** or, simply, **lines of force,** and every magnetic field is assumed to be traversed by such *lines of force*—in fact, to exist by virtue of them. Their position in any plane may be shown by placing

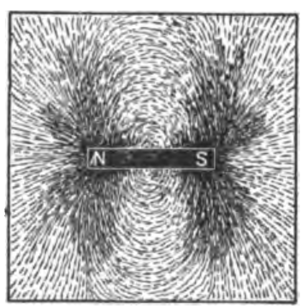


FIG. 11.

a sheet of paper over a magnet, and sprinkling fine iron filings over the paper. In the case of a bar magnet lying on its side, the iron filings will arrange themselves in curved lines extending from the north to the south pole, as shown in Fig. 11. A view of the magnetic field looking towards either pole of a bar magnet would exhibit merely radial lines, as shown by the filings in Fig. 12.

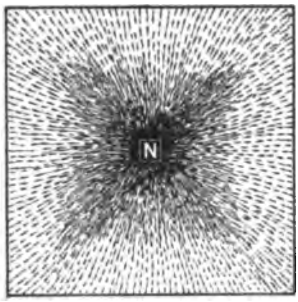


FIG. 12.

Every line of force is assumed to pass out from the north pole, make a complete circuit through the surrounding medium and into the south pole; thence, through the magnet, to the

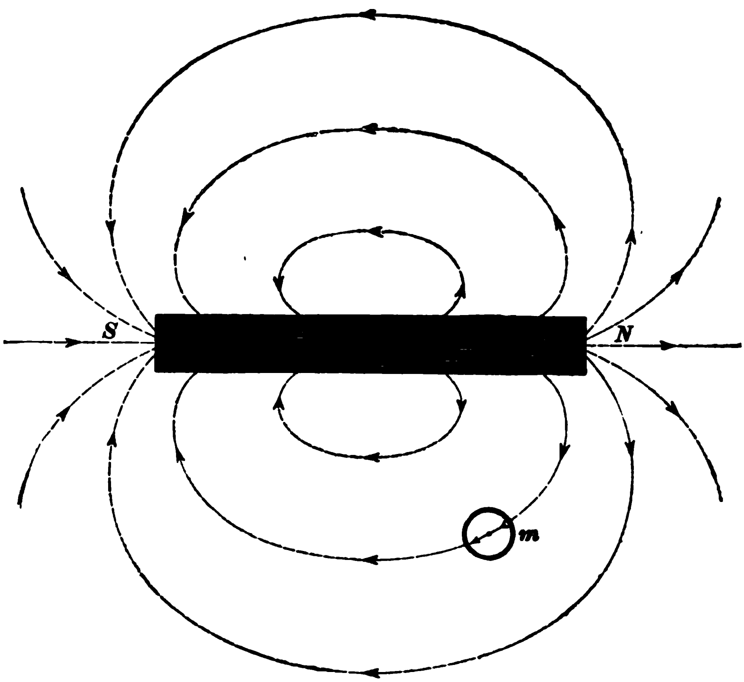


FIG. 13.

north pole again, as shown in Fig. 13. This is called the *direction of the lines of force*, and the path which they take is called the *magnetic circuit.*

23. The *direction of the lines of force* in any magnetic field can be traced by a small, freely suspended magnetic needle, or a small compass such as indicated by *m* in Fig. 13. The north pole of the needle will always point in the direction of the lines of force, the length of the needle lying either parallel or tangent to the lines of force at that point. If the needle be moved bodily in the direction towards which the north pole points, its center or pivot will describe a path coinciding with the direction of the lines of force in that part of the magnetic field.

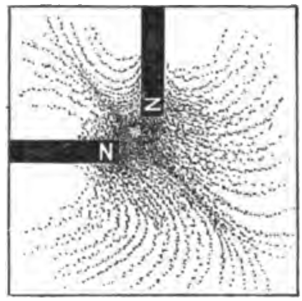


FIG. 14.

NOTE.—In all diagrams, the *direction of the lines of force* will be represented by arrow-heads upon dotted lines.

Lines of force can never intersect each other; when two opposing magnetic fields are brought together, as indicated by the iron filings in Fig. 14 and Fig. 15, the lines of force from each will be crowded and distorted from their original direction until they coincide in direction with those opposing, and form a resultant field in which the direction of the lines of force will depend upon the relative strengths of the two opposing negative fields. The resulting poles thus formed are called **consequent poles.**

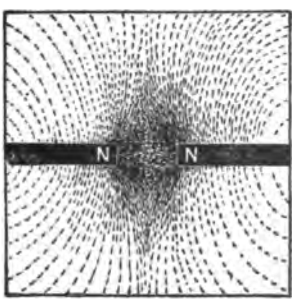


FIG. 15.

In every magnetic field there are certain stresses which produce a *tension* along the lines of force and a *pressure* across them; that is, they tend to *shorten* themselves from end to end, and repel one another as they lie side by side.

24. When a magnetic substance is brought into a magnetic field, the lines of force in that vicinity crowd together and all tend to pass through the substance. If the substance is free to move on an axis (but not bodily) towards the magnet pole, it will always come to rest with its greatest extent or length in the direction of the lines of force. The body will then become a magnet, its south pole being situated where the lines of force enter it, and its north pole where they pass out. The production of magnetism in a magnetic substance in this manner is called **magnetic induction.** The production of artificial magnetism in a hardened steel needle or bar by contact with lodestone is one case of magnetic induction.

The **amount, or quantity, of magnetism** is expressed by the total number of lines of force contained in a magnetic circuit.

Magnetic density is the number of lines of force passing through a unit area measured perpendicularly to their direction.

ELECTROMAGNETISM.

25. If a conductor be placed parallel to the magnetic axis of a compass needle, and a current passed through the

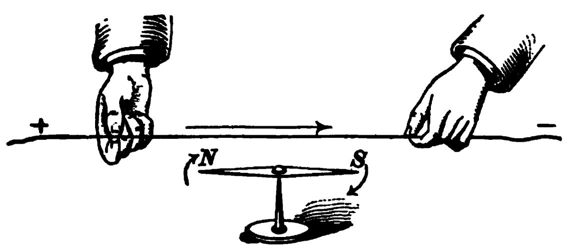


FIG. 16.

conductor in either direction, the needle will tend to place itself at right angles to the conductor, as shown by arrows in Fig. 16; or, in general, an electric current and a magnet exert a mutual force upon each other. From the definition

given in Art. **22,** the space surrounding the conductor is a *magnetic field.* If the conductor is threaded up through a piece of cardboard, and iron filings are sprinkled on the cardboard, they will arrange themselves in concentric circles around the conductor, as represented in Fig. 17. This effect will be observed throughout the entire length of the conductor, and is caused entirely by the current. In fact, every conductor conveying a current of electricity can be imagined as completely surrounded by a sort of magnetic *whirl*, the magnetic density decreasing as the distance from the current increases. (See Fig. 18.)

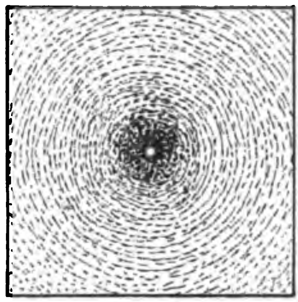


FIG. 17.

26. If the current in a horizontal conductor is flowing *towards* the *north*, and a compass is placed *under* the conductor, Fig. 19, the north pole of the needle will be deflected towards the *west;* by placing the compass *over* the wire, Fig. 20, the north pole of the needle will be deflected towards the *east.* By reversing the direction of the current in the conductor, the needle will point in the opposite direction in each case, respectively.

FIG. 18.

If the conductor is placed *over* the needle, and then bent back *under* it, forming a loop as shown in Fig. 21, the tendency of the current in both top and bottom portions of the wire is to deflect the north pole of the needle in the same direction.

From these experiments, knowing the direction of current in the conductor, the following rule is deduced for the direction of the lines of force around the conductor.

Rule.—*If the current is flowing in the conductor away from the observer, then the direction of the lines of force*

will be around the conductor in the direction of the hands of a watch.

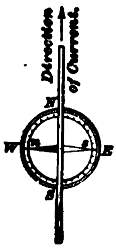


FIG. 19.

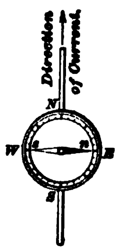


FIG. 20.

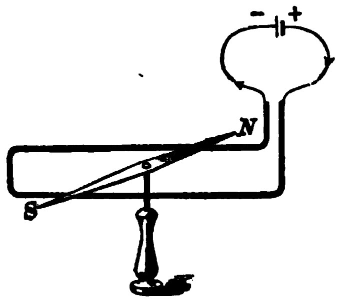


FIG. 21.

The direction of the lines of force around a conductor is indicated in Fig. 22 where the current is assumed to be flowing downwards, that is, piercing the paper.

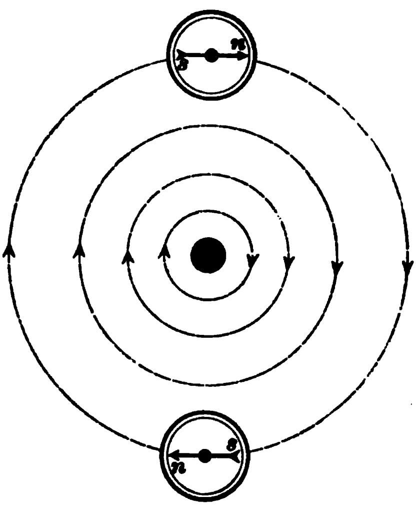


FIG. 22.

27. Two parallel conductors, both transmitting currents of electricity, are either mutually attractive or repellent, depending upon the relative direction of their currents. If the currents are flowing in the *same* direction in both conductors, as represented in Fig. 23, the lines of force will tend to surround both conductors and contract, thus *attracting* the conductors. If, however, the currents are flowing in opposite directions, as in Fig. 24, the lines of force lying between the conductors will have the same direction, and therefore *repel* the conductors.

28. If the conductor carrying the current is bent into the form of a loop, as in Fig. 25, then all the lines of force

around the conductor will thread through the loop in the same direction. By bending the conductor into a long *helix*

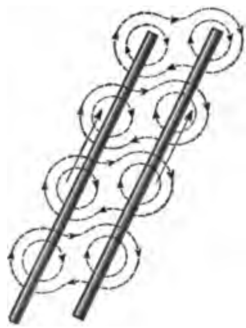


FIG. 23.

FIG. 24.

of several loops, the lines of force around each loop will coincide with those around the adjacent loops, forming several long lines of force which thread through the entire helix, entering at one end and passing out at the other.

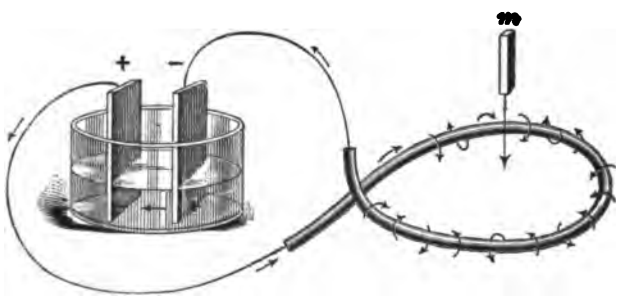


FIG. 25.

The same conditions now exist in the helix as exist in a bar magnet, i. e., the lines of force *pass out* from one end and *enter* the other. In fact, the helix possesses a *north* and a *south pole*, a *neutral line*, and all the properties of attraction and repulsion of a magnet. If it is suspended in a horizontal position and free to turn, it will come to rest pointing in a north and south direction.

A helix made in this manner, around which a current of electricity is circulating, is called a **solenoid.**

29. The **polarity** of a solenoid, that is, the direction of the lines of force which thread through it, depends upon the direction in which the conductor is coiled and the direction of the current in the conductor.

To determine the polarity of a solenoid, knowing the direction of the current:

Rule.—*In looking at the end of the helix, if it is so wound that the current circulates around the helix in the direction of the hands of a watch, that end will be a south pole; if in the other direction, it will be a north pole.*

Fig. 26 represents a conductor coiled in a right-handed helix. If the current starts to flow from the end where the observer stands, that end will be a south pole and the observer will be looking through the helix *in the direction of the lines of force.*

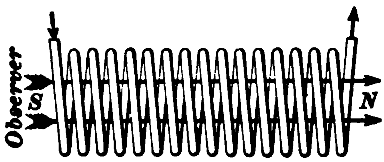


FIG. 26.

The polarity of a solenoid can be changed by reversing the direction of the current in the conductor.

30. In Art. **24** it was stated that when a magnetic substance is brought into a magnetic field, the lines of force in that field crowd together, and all try to pass through that substance; in fact, they will alter their circular shape, and extend a considerable distance from their original position, in order to pass through it. A magnetic substance, therefore, offers a better path for the lines of force than air or other non-magnetic substances.

The facility afforded by any substance to the passage through it of lines of force is called **magnetic permeability,** or, simply, **permeability.**

The *permeability* of all non-magnetic substances, such as air, copper, wood, etc., is taken as 1, or unity. The permeability of soft iron may be as high as 2,000 times that of air. If, therefore, a piece of soft iron be inserted into the magnetic circuit of a solenoid, the number of lines of force will

be greatly increased, and the iron will become highly magnetized.

31. A magnet produced by inserting a magnetic substance into the magnetic circuit of a solenoid is an **electromagnet,** and the magnetic substance around which the current circulates is called the **core.** (See Fig. 27.) The solenoid is generally termed the **magnetizing coil.**

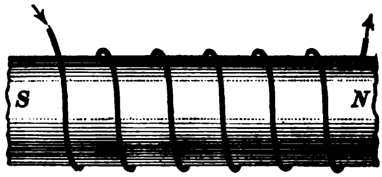


FIG. 27.

In the ordinary form of electromagnet, the magnetizing coil consists of a large number of turns of *insulated* wire, that is, wire covered with a layer or coating of some non-conducting or insulating material, usually silk or cotton; otherwise the current would take a shorter and easier circuit from one coil to the adjacent one, or from the first to the last coil through the iron core without circulating around the magnet.

The simplest form of an electromagnet is the bar magnet. As usually constructed, it consists of a straight bar of iron or steel *B*, fitted into a *spool*, or *bobbin*, made of hard vulcanized rubber or some other inflexible insulating material. The magnetizing coil of fine insulated copper wire *w* is wound in layers in the bobbin, as shown by the cross-section in Fig. 28.

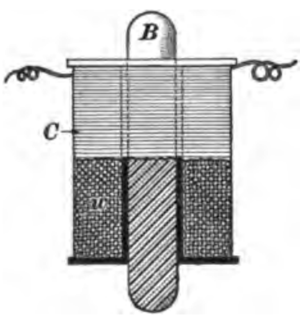


FIG. 28.

The rule for determining the polarity of a solenoid, Art. **29,** is the same for an electromagnet. It makes no difference whether the wire is wound in one layer or in any number of layers, or whether it is wound towards one end and then wound back again over the previous layer towards the other end; so long as the current circulates continually in the same direction around the core, the polarity of the magnet will remain unchanged.

32. The most convenient form of electromagnet for a great variety of uses is the *horseshoe*, or U-*shaped*, electromagnet, Fig. 30. It consists of a bar of iron bent into the shape of a horseshoe with straight ends and provided with two magnetizing coils, one on each end of the magnet. The two ends which are surrounded by the coils are the *cores* of the magnet, and the arc-shaped piece of iron joining them together is known as the **yoke** of the magnet. The ordinary U-shaped electromagnet is made in three parts: namely, two iron cores wound with the magnetizing coils, and a straight bar of iron joining the two cores together for a yoke, as shown in Fig. 29. In looking at the free ends of the two cores, Fig. 30, the current should circulate around one core in an opposite direction to that around the other. If the current circulates around both cores in the same direction, the lines of force produced in the two cores, respectively, oppose one another, forming two like poles at their free ends and a *consequent pole* in the yoke. The total

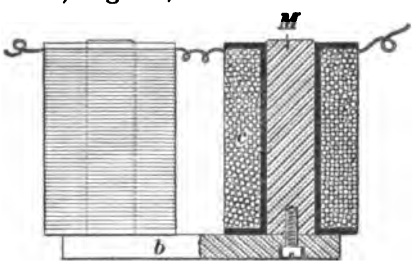


FIG. 29.

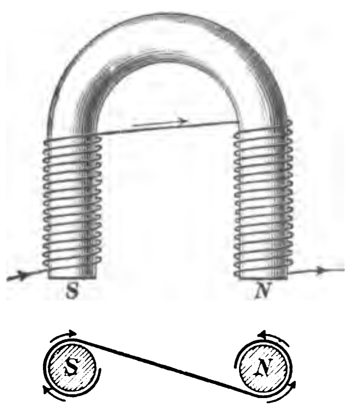


FIG. 30.

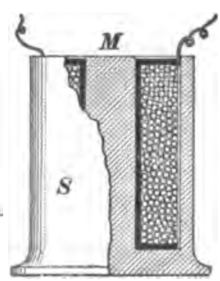


FIG. 31.

number of lines of force produced by both coils will be

greatly diminished, and the magnet will exhibit only a small amount of magnetic attraction.

Another common form of electromagnet is known as the **iron-clad** electromagnet. In its simplest form, Fig. 31, it contains only one magnetizing coil and one core. The core is fastened to a disk-shaped iron yoke, and the magnetic circuit is completed through an iron shell which rises up from the yoke and completely surrounds and protects the coil.

ELECTRICAL UNITS.

33. The three principal units used in practical measurements of a current of electricity are:

The **ampere,** *or the practical unit denoting the rate of flow of an electric current, or the strength of an electric current.*

The **ohm,** *or the practical unit of resistance.*

The **volt,** *or the practical unit of electrical potential or pressure.*

Electromotive force, written E. M. F., or simply E., is the *total generated difference of potential* in any electric source or in any circuit. For example, the total difference of potential developed between the plates of a simple voltaic cell would be the *electromotive force* of that cell.

Ordinarily, the term *electromotive force* is used to express any difference of potential; that is, the electromotive force is the difference of potential between two points.

The relation of these three practical units will be better understood by the analogy of the flow of water through a pipe. The force which causes the water to flow through the pipe is due to the *head* or *pressure;* that which *resists* the flow is the friction of the water against the inside of the pipe, and the amount would vary with circumstances. The *rate of flow*, or the *current*, may be expressed in *gallons per minute*, and is a ratio between the head or pressure and the resistance caused by the friction of the water against the inside of the pipe. For, as the pressure or head *increases*,

the rate of flow or current *increases* in proportion; as the resistance *increases* the current *diminishes*.

In the case of electricity flowing through a conductor, the *electromotive force*, or *potential*, corresponds to the pressure or head of water, and the resistance which a conductor offers to the flow of electricity to the friction of the water against the pipe. The *strength of an electric current*, or the *rate of flow of electricity*, is also a ratio—a ratio of the electromotive force and the resistance of the conductor through which the current is flowing. This ratio as applied to electricity was first discovered by Dr. G. S. Ohm, and has since been called **Ohm's law.**

34. Ohm's Law.—*The strength of an electric current in any circuit is directly proportional to the electromotive force developed in that circuit, and inversely proportional to the resistance of the circuit;* i. e., *it is equal to the electromotive force divided by the resistance.*

Ohm's law is usually expressed algebraically, thus:

$$\text{Strength of current} = \frac{\text{electromotive force}}{\text{resistance}}.$$

If the electromotive force (E) is expressed in *volts* and the resistance (R) in *ohms*, the formula will give the strength of current (C) directly in *amperes;* thus $C = \frac{E}{R}$.

Before giving examples of the application of Ohm s law, the value and significance of each unit will be treated upon separately.

35. The Ampere, or the Unit Strength of Current.—The strength of an electric current can be described as a *quantity* of electricity flowing continuously every second, or, in other words, it is the rate of flow of electricity, just as the current expressed in *gallons per minute* is the *rate of flow* of liquids. When one unit quantity of electricity is flowing continuously every second, then the rate of flow, or the strength of current, is *one ampere;* if two

unit quantities are flowing continuously every second, then the strength of current is *two amperes*, and so on. It makes no difference in the number of amperes whether the current flows for a long period or for only a fraction of a second; if the quantity of electricity that would flow in one second is the same in both cases, then the strength of the current *in amperes* is the same.

The *international ampere* is defined as the strength of an unvarying current, which, when passed through a solution of nitrate of silver and water, deposits silver at the rate of .01725 grain per second.

Electricity possesses neither *weight* nor *extension*, and therefore an electric current can not be measured by the usual methods adopted for measuring liquids and gases. In liquids, the strength of the current is determined by measuring or weighing the actual quantity of the liquid which has passed between two points in a certain time and dividing the result by that time. The strength of an electric current, on the contrary, is determined directly by the effect it produces, and the actual quantity of electricity which has passed between two points in a certain time is afterwards calculated by multiplying the strength of the current by the time.

36. The principal effects produced by an electric current are given in Art. **3**; of these, the one most generally used for measuring is the action of the current upon a magnetic needle, as shown in Art. **25.** The instrument commonly used in laboratory practice for measuring and detecting small currents of electricity is called the **galvanometer.**

The action of the galvanometer is based upon the principle given in Art. **25,** where a magnetic needle, freely suspended in the center of a looped or coiled conductor, is deflected by a current of electricity passing around the coil or loop. In ordinary practice, the needle is suspended either upon a pivot projecting into an agate cup fixed in the needle, or by a fiber suspension, as shown by *F* in

Fig. 32. In the simpler forms of galvanometers, the magnetic needle itself swings over a dial graduated in degrees; in other forms, a light index needle is rigidly attached to the magnetic needle and swings over a similar dial, as indicated by *I* in Fig. 32; and in the more sensitive galvanometers, Fig. 33, a small reflecting mirror is attached to the fiber suspension and reflects a beam of light upon a horizontal scale situated several inches from the galvanometer.

FIG. 32.

In any of these galvanometers, when no current is flowing in the coils, the needle should point in a direction parallel to the length of the coil, Fig. 34. The measuring of

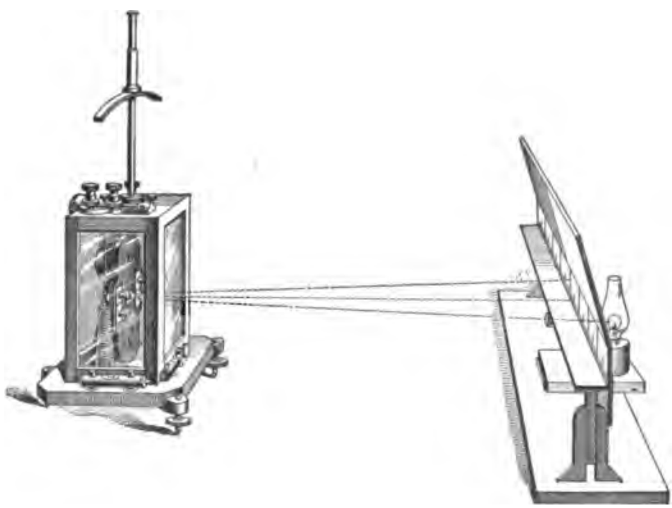


FIG. 33.

currents by most galvanometers depends upon the magnetic needle being held in this position by the magnetic attraction of the earth's magnetism or the attraction of some

adjacent magnet. When a current of electricity passes around the coil, its tendency is to deflect the magnetic needle at right angles to its original position, as explained in Art. **25,** while the tendency of the earth's magnetism is to oppose the movement. The couple thereby produced will cause the needle to be deflected a certain number of degrees from its original position, depending upon the relative strengths of the two magnetic

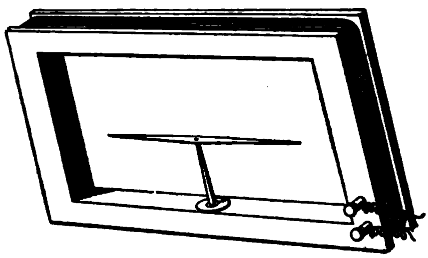


FIG. 34.

fields. The stronger the current in the coil, the greater the deflection. With a galvanometer of standard dimensions and a magnetic field of known strength, such as the earth's magnetism at a convenient place on its surface, a strength of current can be conventionally adopted as a unit which will produce a certain deflection; all other galvanometers can be calibrated from this standard, and their dials graduated to read the strength of current directly in the conventional unit adopted.

37. Commercial and portable instruments are devised for measuring the strength of current directly in *amperes*, and are called **ampere meters,** or simply *ammeters*. The action of the current flowing through the coils in these instruments causes small magnetic needles or other coils of wire to act against either the tension of springs or against gravitational forces. The majority of ammeters are provided with an index needle which travels over a scale or dial graduated in divisions, each division representing one ampere, or fractions or multiples of one ampere.

Fig. 35 shows the general form of a standard Weston ammeter used for commercial testing purposes. The strength of the current flowing in a circuit can be measured directly in amperes by opening the circuit at any convenient

place and connecting the two ends thus formed to the binding-posts *p* and *p'*. The direction of the current in the circuit should be determined beforehand, so that it passes *into* the instrument by the binding-post marked with the positive (+) sign; otherwise the index needle will be deflected off the scale in the wrong direction, which is liable to damage the instrument and cause error in reading when the current passes through in the proper direction.

FIG. 35.

38. The Ohm, or the Unit of Resistance.—In Art. **8** it was stated that the resistance varied in different substances; that is, one substance offers a higher resistance to a current of electricity than another. Electrical resistance, therefore, can be defined as a property of matter, varying with different substances, and in virtue of which such matter opposes or resists the passage of electricity.

The resistance which all substances offer to the passage of an electric current is one of the most important quantities in electrical measurements. In the first place, it is that which determines the strength of an electric current in any circuit in which a difference of potential is constantly maintained, as shown by Ohm's law; and in the second place, the unit of resistance, the *ohm*, is the only unit in electrical measurements for which a material standard can be adopted, other quantities being measured by the effect they produce. The basis of any system of physical measurements is generally some material standard conventionally adopted as a unit, physical measurements in each system being made by comparison with the unit of that system.

The unit of electrical resistance now universally adopted is called the **international ohm.** One international ohm is the resistance offered by a column of pure mercury 106.3 centimeters in length and 1 square millimeter in sectional area at 32° F., or the temperature of melting ice. The dimensions of the column expressed in inches are as follows: length, 41.85 inches; sectional area, .00155 square inch. Hereafter the word "international" will be omitted and simply the word "ohm" used; the *international ohm*, however, as defined above, will always be implied unless otherwise stated.

39. If a given conductor offers a resistance of 2 ohms to a current of 1 ampere, it offers the same amount, no more nor less, to a current of 10 amperes. Hence, *the resistance of a given conductor at equal temperatures is always constant, irrespective of the strength of current flowing through it or the electromotive force of the current.*

40. If the length of a conductor be doubled, its resistance will be doubled; that is, the resistance of a given conductor increases as the length of the conductor increases, the resistance being directly proportional to the length of the conductor.

When it is required to find the resistance of a conductor of which the length is varied, and other conditions remain unchanged, the following formula may be used:

$$r_2 = \frac{r_1 l_2}{l_1}. \qquad \textbf{(1.)}$$

In this formula

r_1 = the original resistance;
r_2 = the required or changed resistance;
l_1 = the original length;
l_2 = the changed length.

As in all examples of proportion, the two lengths must be reduced to the same unit.

By this formula, we see that *the resistance of a conductor after its length is changed is equal to the original resistance*

multiplied by the changed length, and the product divided by the original length.

EXAMPLE.—Find the resistance of 1 mile of copper wire, if the resistance of 10 feet of the same wire be .013 ohm.

SOLUTION.— $r_1 = .013$ ohm; $l_1 = 10$ feet; $l_2 = 1$ mile $= 5{,}280$ feet. Then, by formula **1**, the required resistance $r_2 = \frac{.013 \times 5{,}280}{10} =$ 6.864 ohms. Ans.

41. If the sectional area of a conductor is doubled and other conditions remain unchanged, the resistance will be halved. We may, then, obtain the value of the resistance of a conductor for any change in sectional area by the following formula:

$$r_2 = \frac{r_1 a_1}{a_2}, \qquad (2.)$$

in which r_1 = the original resistance of the conductor;
r_2 = the changed resistance;
a_1 = the original sectional area;
a_2 = the changed sectional area.

From the relations here expressed, it will be seen that the resistance varies inversely as the sectional area; that is, *the resistance of a given conductor diminishes as its sectional area increases.*

The resistance of a conductor is independent of the *shape* of its cross-section. For example, this shape may be circular, square, rectangular, or irregular; if the sectional area be the same in all cases, the resistances will be the same, other conditions being similar.

EXAMPLE.—The resistance of a conductor whose sectional area is .025 sq. in. is .32 ohm; what would be the resistance of the conductor if its sectional area were increased to .125 sq. in. and other conditions remain unchanged?

SOLUTION.— $r_1 = .32$ ohm; $a_1 = .025$ sq. in.; and $a_2 = .125$ sq. in. Then, by formula **2**, the required resistance $r_2 = \frac{r_1\, a_1}{a_2} = \frac{.32 \times .025}{.125} =$ .064 ohm. Ans.

EXAMPLE.—The sectional area of a certain conductor is .01 sq. in. and its resistance is 1 ohm; if its sectional area be decreased to .001 sq. in. and other conditions remain unchanged, what will be the resistance?

SOLUTION.— $r_1 = 1$ ohm; $a_1 = .01$ sq. in; and $a_2 = .001$ sq. in. By formula **2**, the resistance $r_2 = \frac{1 \times .01}{.001} = 10$ ohms. Ans.

42. When comparing resistances of round copper wires the following formula is used:

$$r_2 = \frac{r_1 D^2}{d^2}, \qquad (3.)$$

in which $r_1 =$ the original or known resistance;
$r_2 =$ the required resistance;
$D =$ the original diameter;
$d =$ the changed diameter.

This formula is based on the rule that, since the sectional area of a round conductor is proportional to the square of its diameter (sectional area = diameter^2 × .7854), *the resistance of a round conductor is inversely proportional to the square of its diameter.*

EXAMPLE.—The resistance of a round copper wire .2 in. in diameter is 45 ohms; from this calculate the resistance of a round copper wire .3 in. in diameter, other conditions remaining the same in both cases.

SOLUTION.—In this example, $r_1 = 45$ ohms; $D = .2$ inch; and $d = .3$ inch. Hence, by formula **3**, the required resistance

$$r_2 = \frac{45 \times .2^2}{.3^2} = \frac{45 \times .04}{.09} = 20 \text{ ohms. Ans.}$$

EXAMPLE.—If the resistance of a round German-silver wire $\frac{1}{8}$ in. in diameter is 12.6 ohms, what is the resistance of a round German-silver wire $\frac{1}{16}$ in. in diameter, other conditions being equal in the two cases?

SOLUTION.—In this example, $r_1 = 12.6$ ohms; $D = \frac{1}{8} = .125$ inch; and $d = \frac{1}{16} = .0625$ inch. Hence, by formula **3**,

$$r_2 = \frac{12.6 \times .125^2}{.0625^2} = 50.4 \text{ ohms. Ans.}$$

43. The resistance of two or more conductors connected in *series* (Art. **14**) is equal to the sum of their separate resistances. For example, if four conductors having separate

resistances of 8, 12, 22, and 34 ohms, respectively, are connected in series, their total or joint resistance would be $8 + 12 + 22 + 34 = 76$ ohms.

44. The **microhm** is a unit of resistance devised to facilitate calculations and measurements of exceedingly small resistances, and is equal to *one millionth* $\left(\frac{1}{1,000,000}\right)$ of an *ohm*. Hence, to express the resistance in *microhms*, multiply the resistance in *ohms* by 1,000,000; and, conversely, to express the resistance in *ohms*, divide the resistance in *microhms* by 1,000,000. For example, .75 ohm $= .75 \times 1,000,000 = 750,000$ microhms; or, 750,000 microhms $= 750,000 \div 1,000,000 = .75$ ohm.

45. The **megohm** is a unit of resistance devised to facilitate calculations and measurements of exceedingly large resistances, and is equal to 1,000,000 ohms. Therefore, to express the resistance in *megohms*, divide the resistance in *ohms* by 1,000,000; and, conversely, to express the resistance in *ohms*, multiply the resistance in *megohms* by 1,000,000. For example, 850,000 ohms $= \frac{850,000}{1,000,000} = .85$ megohm; or, .85 megohm $= .85 \times 1,000,000 = 850,000$ ohms.

The megohm is used chiefly to measure the resistance of bad conductors and insulators.

46. In order to compare the resistances of different substances, the dimensions of the pieces to be measured must be equal; for, by changing its dimensions, a good conductor may be made to offer the same resistance as an inferior one. Under like conditions, annealed silver offers the least resistance of all known substances. Soft, annealed copper comes next on the list, and then follow all other metals and conductors.

The resistance of a given conductor, however, is not always constant; it changes with the temperature of the conductor. In all metals, the resistance *increases* as the temperature rises; in liquids and carbons, the resistance *decreases* as the

temperature rises. The amount of variations in the resistance caused by a change in temperature for one degree is called the **temperature coefficient.** The temperature coefficients for the common metals are given in Table 1 for degrees Fahrenheit. These coefficients, however, only hold true for a limited change of temperature, and should not be used with extreme changes. The rules given below, making use of these coefficients, are not absolutely accurate, but enough so for practical purposes.

To find the resistance of a conductor after its temperature has risen, knowing its original resistance and the number of degrees rise, other conditions remaining unchanged:

Let r_1 = the original resistance;
r_2 = the resistance after a change in temperature;
k = the temperature coefficient;
t = rise or fall in temperature, degrees Fahrenheit.

Then, for a *rise* in temperature,

$$r_2 = r_1 (1 + t\,k). \qquad \textbf{(4.)}$$

That is, *the resistance of a conductor after its temperature has risen may be obtained by multiplying the original resistance by one plus the product of the number of degrees rise and the temperature coefficient.*

EXAMPLE.—The resistance of a piece of copper wire at 32° F. is 40 ohms; determine its resistance when its temperature is 52° F.

SOLUTION.— $R = 40$ ohms;
$k = .002155$ (from Table 1);
$t = 52 - 32 = 20$ degrees.

By formula **4**, the required resistance $r_2 = r_1 (1 + t\,k) = 40 (1 + 20 \times .002155) = 40 \times 1.0431 = 41.724$ ohms. Ans.

47. To find the resistance of a conductor after its temperature has fallen, knowing its original resistance and the number of degrees fall, other conditions remaining unchanged:

For a *fall* in temperature, $r_2 = \frac{r_1}{1 + t\,k}$. **(5.)**

That is, *the resistance of a conductor after its temperature has fallen may be obtained by dividing the original resistance by one plus the product of the number of degrees fall and the temperature coefficient.*

EXAMPLE.—The original resistance of a piece of German-silver wire is 16 ohms; find its resistance after its temperature has fallen 22° F.

SOLUTION.— $R = 16$ ohms;
$k \doteq .000244$ (from Table 1);
$t = 22°$ F.

By formula **5**, the required resistance

$$r_2 = \frac{r_1}{1 + tk} = \frac{16}{1 + 22 \times .000244} = \frac{16}{1.005368} = 15.9145 \text{ ohms. Ans.}$$

48. Specific resistance is the term given to the resistance of substances of unit length and unit sectional area at some standard temperature. In what follows, the specific resistance of a substance is the resistance of a piece of that substance one inch in length and one square inch in sectional area at 32° F., that is, at the temperature of melting ice; this may also be expressed as the resistance of a cube of that substance taken between two opposing faces.

A list of the common metals is given in Table 1, in the order of their relative resistances, beginning with silver, which offers the least resistance. The first column of figures gives the *specific resistance* in microhms of 1 cubic inch of the corresponding metal at 32° F. By applying formula **1**, the resistance of any conductor of known dimensions which is made of one of the metals in the table can be determined. The second column of figures gives the relative resistance of the different metals compared with silver. For example, the resistance of mercury is 62.73 times the resistance of silver, or the resistance of iron is 6.46 times the resistance of silver, and so on.

EXAMPLE.—Find the resistance in ohms of a round column of mercury 70" high and .05" in diameter. Ans. 1.3244 ohms.

EXAMPLE.—Find the resistance in ohms of 1 mile of square iron wire (annealed) .1" on a side. Ans. 24.2352 ohms.

TABLE 1.

Name of Metal.	Resistance, Microhms per Cu. In.	Relative Resistance.	Temperature Coefficient.
Silver, annealed.......	.5921	1.000	.002094
Copper, annealed......	.6292	1.063	.002155
Silver, hard-drawn....	.6433	1.086	.002094
Copper, hard-drawn...	.6433	1.086	.002155
Gold, annealed........	.8102	1.369	.002028
Gold, hard-drawn.....	.8247	1.393	.002028
Aluminum, annealed..	1.1470	1.935	
Zinc, pressed.........	2.2150	3.741	.002028
Platinum, annealed....	3.5650	6.022	
Iron, annealed........	3.8250	6.460	
Nickel, annealed......	4.9070	8.285	
Tin, pressed..........	5.2020	8.784	.002028
Lead, pressed.........	7.7280	13.050	.002150
German Silver........	8.2400	13.920	.000244
Antimony, pressed....	13.9800	23.600	.002161
Mercury..............	37.1500	62.730	.000400
Bismuth, pressed......	51.6500	87.230	.001967

49. In a simple voltaic cell the *internal* resistance—that is, the resistance of the two plates and the electrolyte—is of great importance, for it determines the maximum strength of current that can possibly be obtained from the cell. In the common forms of cells, the internal resistance may be excessively large, owing to the resistance of the electrolyte, the specific resistance of ordinary liquids used as electrolytes being from 1 to 20 million times that of the common metals. In liquids, as in all conductors, the resistance increases as the length of the circuit increases, and diminishes as its sectional area increases. Hence, the internal resistance of a simple voltaic cell is reduced by decreasing the distance between the plates or elements and by increasing their active surfaces. The internal resistance

of the ordinary forms of cells varies from about .2 to 20 ohms.

50. For practical and commercial testing, the standard column of mercury, representing the resistance of one ohm, has been replaced by a coil of wire, usually a platinum-silver alloy. The coil is carefully calibrated to offer a resistance of exactly one ohm at some convenient temperature, and is enclosed in a metallic case, the connections to the two ends of the coils being made by two heavy terminals of copper wire passing up through the hard-rubber cover. Such coils are known as *standard ohm coils.* The commercial form of standard ohm coils is shown in Fig. 36.

FIG. 36.

51. An apparatus called a **resistance-box** or **rheostat** is largely used for reducing or controlling the strength of currents in various circuits. Such rheostats are connected directly in *series* or *shunt* with the circuit, and are termed *dead resistances.* The resistance in these rheostats is usually made adjustable; that is, the amount of resistance which they offer may be varied at the will of the operator by the use of a sliding contact, or by removable plugs. Rheostats in which the amount of resistance is varied by sliding contacts are used mostly where accuracy is of less importance and where the currents are comparatively large.

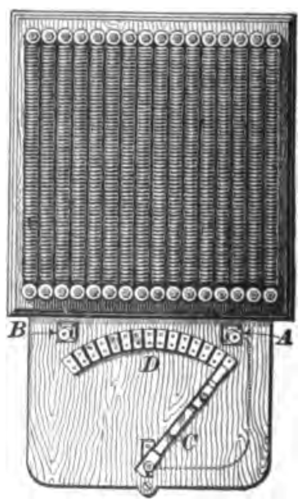


FIG. 37.

Fig. 37 shows a typical form of sliding-contact rheostat. In this particular rheostat, the coils of resistance wire are connected to a row of contact pieces *D*, as shown in the diagram, Fig. 38. The current enters the rheostat through the terminal *A*, passes through the movable arm *C*, and then through all the resistance-coils between the contact piece on which the arm rests and the terminal *B*. When the arm rests upon the first contact piece, as shown by the full lines in this diagram, all of the resistance is said to be *in circuit;* that is, the current passes through all the coils. By moving the arm to the left, towards the terminal *B*, as shown by the dotted lines, the coils connected to the contact pieces which have been passed over by the arm are said to be *cut out* of circuit, and the current passes through the remaining coils only.

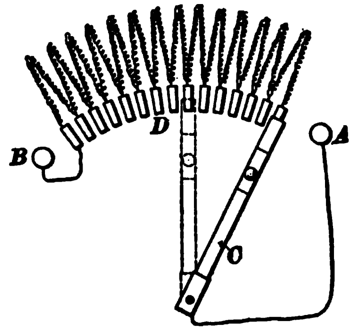


FIG. 38.

52. Rheostats in which the resistance is adjusted by means of removable plugs are employed in laboratory practice, where small currents are used and where great accuracy is required. The resistance-coils in these rheostats are enclosed in a wooden box, and the actual resistance of each coil is carefully determined. A resistance-box offering 10,000 ohms resistance is shown in Fig. 39, the separate coils offering resistances from one ohm up to 5,000 ohms. The operation of adjusting the resistance by means of the removable plugs can be seen from the diagram in Fig. 40. The contact pieces *a*, *b*, *c*, etc., are arranged side by side on the top of the case and are separated from each other by a small air-space. The ends of each contact piece are provided with a tapered recess in such a manner as to allow a metallic plug to be inserted between them and thereby connect the two together electrically. The current passes into the

rheostat by the terminal *A*, and when all the plugs are removed flows consecutively through all the coils *1*, *2*, *3*, *4*, *5*.

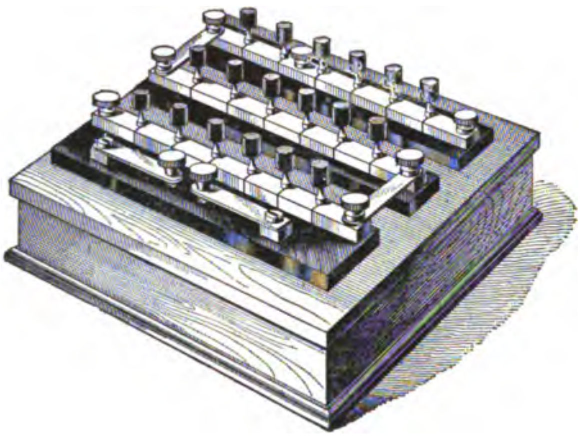


FIG. 39.

and *6* to the terminal *B*. The total resistance of the rheostat can be lowered by inserting the plug *P* between the

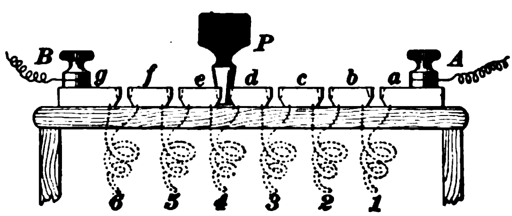


FIG. 40.

contact pieces; this operation *short-circuits*, or *cuts out*, the particular coil connected to the two contact pieces, or, in other words, the current, instead of flowing through the coils, passes directly from one contact piece to the other through the metallic plug.

53. Electrical resistance may be measured by an apparatus called a **Wheatstone bridge.** A bridge, when completed, ready for taking measurements, consists of three main parts: (1) an adjustable resistance-box containing a

number of coils, the exact resistance of each coil being known; (2) a galvanometer for detecting small currents, and (3) a battery of several cells. The coils of the resistance-box are divided into three groups, two of which are called **proportional** or **balance arms,** and the third is known as the **adjustable arm.** Each proportional arm is composed of three and sometimes four coils of 1, 10, 100, and 1,000 ohms resistance, respectively. The adjustable arm contains a large number of coils ranging from .1 ohm up to 10,000 ohms.

The operation of the bridge depends upon the principle of the relative difference of potential between two points in a divided circuit of two branches. The electrical connections of the bridge are shown in the diagram, Fig. 41.

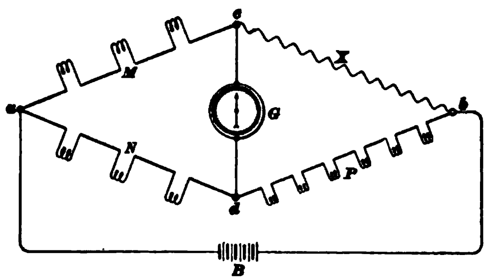


FIG. 41.

M represents the resistance of one of the balance arms, which will be termed for convenience the *upper* balance arm; *N* represents the resistance of the other balance arm, which will be termed the *lower* balance arm; *P* represents the resistance of the adjustable arm, and *X* represents an unknown resistance, the value of which is to be determined. One terminal of the detecting galvanometer *G* is connected at *c*, the junction of the upper balance arm and the unknown resistance; the other terminal is connected at *d*, the junction of the lower balance arm and the adjustable arm. One pole of the battery is connected at *a*, the junction of the two balance arms; the other pole at *b*, the junction of the adjustable resistance and the unknown resistance. The current from the battery divides at *a*, part

of it flowing through resistances M and X, and the rest through N and P. When the resistances M, N, P, and X fulfil the proportion $\frac{M}{N} = \frac{X}{P}$, then the two points c and d will have the same potential, and no current will flow through the galvanometer G. Since the resistances of M, N, and P are known, the resistance of X will be given by the fundamental equation $X = \frac{M}{N} \times P$, when the arms are so adjusted as to cause no deflection of the galvanometer. For example, suppose that the two ends of a copper wire are connected to the terminals b and c, and after adjusting the resistance in the arm so that the galvanometer shows no deflection, the resistances of the different arms read as follows: $M = 1$ ohm, $N = 100$ ohms, and $P = 112$ ohms. Then, substituting these values in the fundamental equation gives

$$X = \frac{M}{N} \times P = \frac{1}{100} \times 112 = 1.12 \text{ ohms.}$$

54. The actual various forms of resistance-boxes used with the bridges differ widely from the diagram, but all are

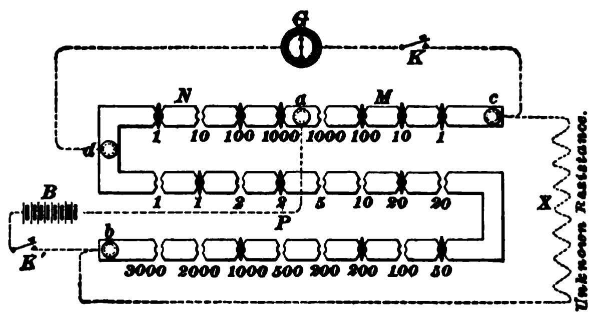


FIG. 42.

based upon this same principle and fundamental equation. A common pattern of resistance-box for this purpose is constructed similar to the adjustable rheostat, as previously described, where the adjustments are made with removable plugs. Ordinarily the contact pieces are arranged in the shape of a letter S, and the galvanometer and battery

circuits are connected as shown in Fig. 42. The position of the two balance arms and the adjustable arm can be readily seen by comparing the connections of the battery and galvanometer circuits with those in the original diagram. K and K' represent keys for opening the circuits when the plugs are withdrawn or inserted in varying the resistance or when the bridge is not in use. In this particular case, the 1,000-ohm plug in the upper balance arm is supposed to be drawn, and therefore $M = 1,000$ ohms. In the lower balance arm the 10-ohm plug is supposed to be drawn, and therefore $N = 10$ ohms. In the adjustable arm the following plugs are supposed to be drawn: 1, 2, 5, 10, 20, 100, 200, 500, 2,000, and 3,000 ohms; therefore, the resistance P is the sum of these resistances, or 5,838 ohms. If, under these conditions, there is no deflection of the galvanometer when the two keys K and K' are pressed and both circuits are closed, the resistance of X will be 583,800 ohms; for substituting the values of M, N, and P in the fundamental equation gives $X = \frac{M}{N} \times P = \frac{1,000}{10} \times 5,838 = 583,800$ ohms.

Fig. 43 shows a special pattern of resistance-box for a Wheatstone bridge, in which the coils of the adjustable

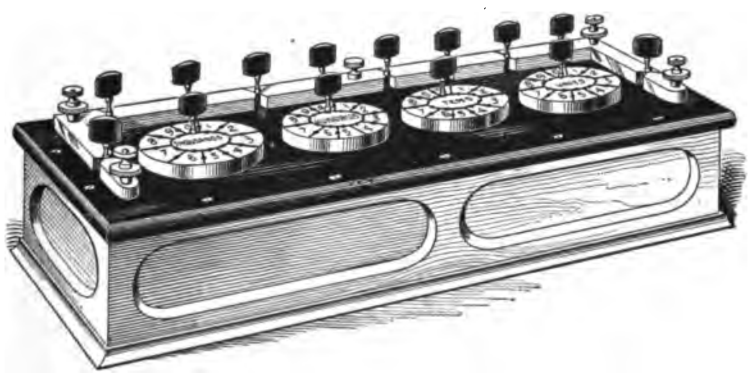


FIG. 43.

arm are arranged in the form of four dials. This pattern is known as the *dial* pattern, and is widely used in making resistance measurements.

EXAMPLE.—The diagram in Fig. 44 represents a particular type of Wheatstone's bridge to which a battery and galvanometer are properly connected for measuring unknown resistances. An unknown resistance x is connected to the terminals A and H; when the plugs a, e, f,

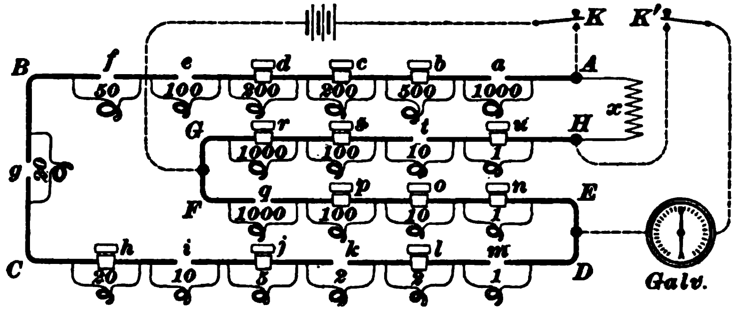


FIG. 44.

g, i, k, m, q, and t are drawn, and when both the contact keys K and K' are pressed, the galvanometer shows no deflection. Determine the resistance of x.

SOLUTION.—From the connections of the galvanometer and battery circuits, it will be seen that the resistance-coils in line $G\,H$ represent the upper balance arm M of the bridge; that the coils in the line $E\,F$ represent the lower balance arm N, and that the coils in the lines $A\,B$ and $C\,D$ represent the adjustable arm P. From the fundamental equation of the Wheatstone bridge, X (the unknown resistance) $= \frac{M}{N} \times P$. In this particular case, the plug t in the upper arm is drawn; hence, $M = 10$ ohms; in the lower arm q is drawn; hence, $N = 1{,}000$ ohms; and in the adjustable arm, the plugs a, e, f, g, i, k, and m are drawn; hence, $P = 1{,}000 + 100 + 50 + 20 + 10 + 2 + 1 = 1{,}183$ ohms. Substituting these values in the fundamental equation gives $X = \frac{M}{N} \times P = \frac{10}{1{,}000} \times 1{,}183 = 11.83$ ohms. Ans.

55. The Volt, or the Practical Unit of Electromotive Force.—In mechanics, pressures of all kinds are measured by the *effects* they produce; similarly, in electrotechnics, *potential* is measured by the effect it produces.

It has been shown that electrical potential will cause an electric current to flow against the resistance of a conductor, and also how the units of resistance and current are obtained. It follows that a *unit potential* would be that

electromotive force which would maintain a current of unit strength in a circuit whose resistance is unity. By definition, therefore, the *volt*, or *the practical unit of potential*, is that electromotive force which will maintain a current of *one ampere* in a circuit whose resistance is *one ohm*. With a known resistance in ohms and a known strength of current in amperes, the electromotive force in volts is determined by Ohm's law, Art. **34**; for, by transposing, $E = C R$.

This method of determining the potential of a circuit can be readily shown by the following illustration: Suppose, for example, it is desired to determine the electromotive force in volts required to drive a current of 2 amperes through a certain copper wire. In the first place, the resistance of the copper wire is found by Wheatstone's bridge as previously described. For convenience, it is assumed that its resistance is found to be 1.2 ohms. Then the electromotive force E required to drive 2 amperes through the wire will be 2.4 volts; for, by substituting, $E = C R = 2 \times 1.2 =$ 2.4 volts.

The maximum difference of potential developed by any single voltaic couple placed in any electrolyte is about 2.25 volts; in the common forms of cells, the difference of potential developed averages from .75 to 1.75 volts.

56. When several cells are connected in *series*, the total electromotive force developed will be equal to the sum of the electromotive forces developed by the separate cells; or, if the cells are composed of the same voltaic elements, the total electromotive force developed will be equal to the electromotive force of one cell, multiplied by the number of cells in series. For example, a battery is composed of 12 cells connected in series, and the electromotive force in each cell is 1.5 volts; the total electromotive force of the battery is, therefore, $1.5 \times 12 = 18$ volts.

Connecting cells in *parallel*, or *multiple-arc*, does not increase the electromotive force of a battery; the electromotive force will always be equal to the electromotive force of one cell, no matter how many cells are connected to the

main conductors, provided, of course, that all cells develop equal electromotive forces.

57. Measuring instruments called **voltmeters** have been devised for indicating electromotive forces and differences of potential directly in volts. Principal among these are the *Cardew* and *Weston* voltmeters.

The **Cardew** voltmeter, Fig. 45, depends for its operation upon the linear expansion of a metallic wire when heated by an electric current. The expansion wire *w* is enclosed in a long cylindrical case *a*, and is attached in such a way that its expansion causes a small grooved wheel on the axis of the index needle to revolve in one direction when the wire expands or lengthens, and in the opposite direction when the wire contracts or shortens. The movements of this wheel cause the index *b* to move over the scale. Since the resistance is nearly constant, the current that will flow is proportional to the E. M. F.; the greater the E. M. F. the more the wire will be expanded, and the greater will be the consequent deflection. The resistance of the wire, however, is so large as to permit only a weak current to pass through it when the needle is deflected over the entire scale. A Cardew voltmeter which indicates up to 100 volts has a resistance of about 500 ohms. The circular scale is divided into small divisions, each representing one volt, or fractions, or multiples of one volt.

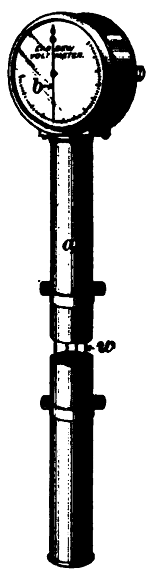


FIG. 45.

58. The **Weston** voltmeter, Fig. 46, is based upon the same principles as the Weston ammeter, and in appearance is quite similar to it. Its internal resistance, as in all voltmeters, is exceedingly large; the resistance of a Weston voltmeter for indicating up to 150 volts is about 19,000 ohms, while the resistance of a Weston ammeter, measuring strengths of currents up to 15 amperes, is only .0022 ohm. It will be seen that, owing to the great resistance, the

current passing through a voltmeter is exceedingly small. For example, in the instrument described above, when indicating 150 volts, the current, by Ohm's law, is only 150 ÷ 19,000 = .0079 ampere. All voltmeters are provided with at least two terminals, or binding-posts, such as p and p', Fig. 46. Connections are made by two separate conductors, called *voltmeter leads*, from these binding-posts to two points between which the difference of potential, or the electromotive force, is to be measured.

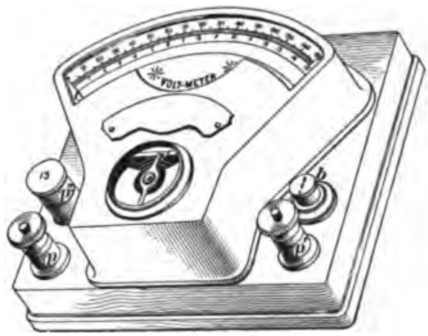


FIG. 46.

The Weston voltmeters usually have a third binding-post p'', which when used with p' corresponds with a second graduated scale situated directly under the main scale, one division of the upper scale having the value of two lower divisions. The majority of voltmeters are also provided with a contact button b, which when pressed closes the circuit and allows the index needle to be deflected by the current. When the pressure upon the button is relaxed, the circuit is opened, and the index needle returns to the zero mark.

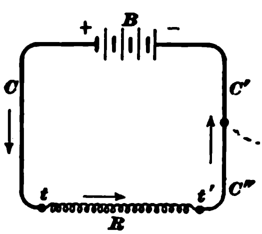


FIG. 47.

59. The methods of connecting voltmeters and ammeters for measuring electromotive forces and currents of various circuits should be thoroughly understood. Suppose, for example, that the terminals of a battery composed of four cells connected in series are connected to an unknown resistance, and it is desired to know the strength of current flowing through the circuit, and also the difference of potential required to drive that current through

the unknown resistance when the only instruments available are an ammeter and a voltmeter. In Fig. 47 let B represent the battery and R the unknown resistance; C, C', and C'' are three large conductors for making necessary connections. With the connections as shown, there is practically a continuous current flowing through the closed circuit, that is, from the battery through the conductors and the unknown resistance. The first step is to determine the strength of this current by the use of an ammeter. Assuming that the battery is constant, that is, that the electromotive force developed in it does not vary, then, so long as the resistance of the circuit is not altered, the strength of the current will remain unchanged and *will be the same in all parts of the circuit.* Hence, if an ammeter be inserted in any part of the circuit, as between C' and C'', Fig. 48, it will measure the total strength of current flowing through the entire circuit. As has been stated, the internal resistance of the ammeter is so small that its insertion makes no appreciable change in the total resistance of the circuit, and therefore does not to any extent affect the current flowing. For convenience, assume that the strength of the current flowing in the circuit is found to be 1.2 amperes. The next operation is to find the electromotive force required to drive a current of 1.2 amperes through the resistance R; or, in other words, to find the difference of potential between the terminals t and t' when a current of 1.2 amperes is flowing in the circuit. This is accomplished by connecting the two terminals t and t', Fig. 49, of the unknown resistance R, to the two binding-posts p and p' of the voltmeter $V. M.$ by two voltmeter leads l and l'. Any small wires of reasonable length can be used for voltmeter leads, as the current they transmit is exceedingly weak, owing to the extremely high resistance of the voltmeter. After pressing the contact button, assume the needle indicates a potential of 6 volts; this, then, is the

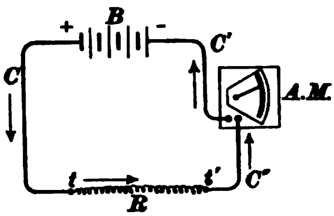


Fig. 48.

electromotive force required to force a current of 1.2 amperes through the unknown resistance R; or, in other words, the difference of potential between the terminals t and t' is 6 volts. From these readings of the current and voltage, and by the application of Ohm's law, the resistance R of the circuit between t and t' can be determined. By algebra, Ohm's law can be transposed from the equation $C = \frac{E}{R}$ to $R = \frac{E}{C}$ and be equally true; this signifies that the resistance R of any conductor, or circuit, is equal to the electromotive force, or the difference of potential E in volts, divided by the strength of current C in amperes, flowing through that circuit or conductor. In the previous case, it has been found that it requires an electromotive force of 6 volts to drive a current of 1.2 amperes through the resistance R; hence, from Ohm's law $R = \frac{E}{C} = \frac{6}{1.2} = 5$ ohms.

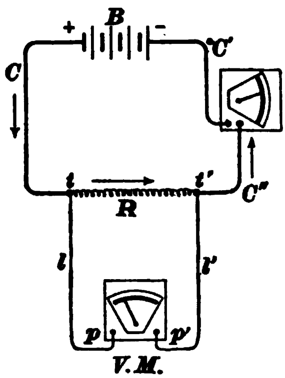


FIG. 49.

APPLICATIONS OF OHM'S LAW.

TO CLOSED CIRCUITS.

60. The following facts are to be carefully noted regarding the application of Ohm's law to closed circuits:

The strength of current (**C**) *is the same in all parts of a closed circuit, except in the cases of derived circuits, where the sum of the currents in the separate branches is always equal to the current in the main or undivided circuit.*

The resistance (**R**) *is the resistance of the internal circuit plus the resistance of the external circuit.*

The electromotive force (**E**) *in a closed circuit is the total generated difference of potential in that circuit.*

61. The following formula may be used to determine the strength of current in amperes flowing in a closed circuit when the electromotive force and the total resistance are known:

$$C = \frac{E}{R}, \qquad \textbf{(6.)}$$

where C = current in amperes;
E = electromotive force in volts;
R = resistance in ohms.

That is to say, *the strength of current in amperes is found by dividing the electromotive force in volts by the total resistance in ohms.*

EXAMPLE.—The two electrodes of a simple voltaic cell are connected by a conductor whose resistance is 1.6 ohms. If the internal resistance of the cell is 5 ohms and the total electromotive force developed is 1.75 volts, what is the strength of current flowing in the circuit?

SOLUTION.—Let r_i = the internal resistance and r_e = the resistance of the copper wire. Then, $R = r_i + r_e = 1.6 + 5 = 6.6$ ohms, the total resistance of the circuit. Then, by formula **6**, the current

$$C = \frac{E}{R} = \frac{1.75}{6.6} = .265 \text{ ampere. Ans.}$$

62. The following formula may be used to find the total resistance in ohms of a closed circuit when the electromotive force and the strength of current are known:

$$R = \frac{E}{C}, \qquad \textbf{(7.)}$$

the letters having the same significance as in formula **6.** By formula **7** it will be seen that *the resistance in ohms of a closed circuit is found by dividing the electromotive force in volts by the current in amperes.*

EXAMPLE.—The total electromotive force developed in a closed circuit is 1.8 volts and the strength of the current flowing is .6 ampere; find the resistance in ohms.

SOLUTION.—By formula **7** the resistance

$$R = \frac{E}{C} = \frac{1.8}{.6} = 3 \text{ ohms. Ans.}$$

63. The following formula may be used to find the total electromotive force in volts developed in a closed circuit when the strength of current and the total resistance are known:

$$E = CR. \qquad \textbf{(8.)}$$

The letters have the same meaning as in formulas **6** and **7**. We find here that *the electromotive force in volts developed in a closed circuit is obtained by multiplying together the current in amperes and the resistance in ohms.*

EXAMPLE.—The internal resistance of a closed circuit is 2 ohms and the external resistance is 3 ohms; if the current flowing is .4 ampere, what is the electromotive force developed?

SOLUTION.—Let r_i = the internal resistance and r_e = the external resistance. Then, $R = r_i + r_e = 2 + 3 = 5$ ohms. By formula **8**, the electromotive force $E = CR = .4 \times 5 = 2.0$ volts. Ans.

TO DROP, OR LOSS, OF POTENTIAL.

64. Referring again to water flowing in a pipe, it is evident that although the *quantity* of water which passes is the same at any cross-section of the pipe, the *pressure per square inch* is not the same. Even in the case of a horizontal pipe of the same diameter throughout, the water when flowing suffers a *loss* of head or pressure. It is this difference of pressure that causes the water to flow between two points against the friction of the pipe.

This is precisely similar to a current of electricity flowing through a conductor. Though the *quantity of electricity* that flows is equal at all cross-sections, the electromotive force is by no means the same at all points along the conductor. It suffers a loss, or drop, of electrical potential in the direction in which the current is flowing, and it is this difference of electrical potential that causes the electricity to flow against the resistance of the conductor. *Ohm's law* not only gives the strength of the current in a closed circuit, but also the *difference of potential* in volts along that circuit. The difference of potential (E') in volts between any two points along a circuit is equal to the product of the

strength of the current (C) in amperes and the resistance (R') in ohms of that part of the circuit between those two points, or $E' = C\,R'$, which is an example of the use of formula **8.** E' also represents the *loss*, or *drop*, of potential in volts between the two points. If any two of these quantities are known, the third can be readily found; for, by transposing, $C = \frac{E'}{R'}$ and $R' = \frac{E'}{C}$, as already given in formulas **6** and **7.**

EXAMPLE.—Fig. 50 represents part of a circuit in which a current of 3 amperes is flowing. The resistance from a to b is 1.5 ohms, from b to c is 2.3 ohms, and from c to d is 3.6 ohms. Find the difference of potential between a and b, b and c, c and d, and a and d.

FIG. 50.

SOLUTION.—Since, by formula **8,** $E' = C\,R'$, then,
the difference of potential between a and $b = 3 \times 1.5 = 4.5$ volts.
" " " " " b and $c = 3 \times 2.3 = 6.9$ "
" " " " " c and $d = 3 \times 3.6 = 10.8$ "
" " " " " a and $d = 4.5 + 6.9 + 10.8 =$ 22.2 volts; or, in other words, the *loss*, or *drop*, of potential caused by a current of 3 amperes flowing between a and d is 22.2 volts.

65. In a great many cases it is desirable to have the current flow from the source a long distance to some electrical receptive device and return without causing an excessive drop, or loss, of potential in the conductors leading to and from the two places. In such circuits, the greater part of the total generated electromotive force is expended in the receptive device itself, and only a small fraction of it is lost in the rest of the circuit. Under these conditions, it is customary to decide upon a certain *drop, or loss, of potential* beforehand, and from that and the current calculate the resistance of the two conductors.

EXAMPLE.—It is desired to transmit a current of 5 amperes to an electrical device situated 500 feet from the source; the total generated E. M. F. is 120 volts, and only $\frac{1}{10}$ of this potential is to be lost in the conductors leading to and from the receptive device. (a) Find the resistance of the two conductors, and (b) find the resistance per foot of the conductors, assuming each to be 500 feet long.

SOLUTION.—(*a*) $\frac{1}{10}$ of 120 volts = 12 volts, which represents the *drop*, or *loss*, of potential on the two conductors. Let $E' = 12$ volts; $C = 5$ amperes, and R' = the total resistance of the two conductors. Then, by formula **7**, $R' = \frac{E'}{C} = \frac{12}{5} = 2.4$ ohms. Ans.

(*b*) The resistance per foot of the conductor is found by formula **1**. In this case, $r_1 = 2.4$ ohms; $l_1 = 1{,}000$ feet; $l_2 = 1$ foot. Then the resistance per foot,

$$r_2 = \frac{2.4 \times 1}{1{,}000} = .0024 \text{ ohm. Ans.}$$

TO VOLTAIC CELLS.

66. The difference of potential between the two electrodes of a simple voltaic cell when no current is flowing—that is, when the circuit is open—is always equal to the total electromotive force developed within the cell; but when a current is flowing—that is, when the circuit is *closed*—a certain amount of potential is expended in forcing the current through the internal resistance of the cell itself. Hence, the difference of potential between the two electrodes when the circuit is closed is always smaller than when the circuit is open. This difference of potential between the two electrodes when the circuit is closed is sometimes called the *available* or *external* electromotive force, to distinguish it from the *internal* or *total generated* electromotive force.

67. To find the available electromotive force of a cell, let E = the total generated E. M. F.;
E' = *available* E. M. F. when the circuit is closed;
C = the current flowing when the circuit is closed;
r_i = the internal resistance of the cell.

Then, the drop, or loss, of potential in the cell = $C r_i$, and the available electromotive force,

$$E' = E - C r_i. \qquad \textbf{(9.)}$$

The available electromotive force of a cell is equal to the difference between the total generated electromotive force and the potential expended in forcing the current through the internal

resistance of the cell when the circuit is closed. From Ohm's law, this loss, or drop, of potential in the cell itself is equal to the product of the internal resistance in ohms and the strength of the current in amperes flowing through the circuit.

EXAMPLE.—In a voltaic cell, the total generated E. M. F. is 2.2 volts and the internal resistance is .8 ohm. If a current of 1.2 amperes flows through the cell when the circuit is closed, what is the available E. M. F., or, in other words, the difference of potential between the two electrodes?

SOLUTION.—Let E' = the available E. M. F.; E = the total generated electromotive force; C = the current in amperes; and r_i = the internal resistance.

Then, by formula **9**,

$$E' = E - C r_i = 2.2 - (1.2 \times .8) = 1.24 \text{ volts. Ans.}$$

TO DERIVED CIRCUITS.

68. In treating upon derived circuits, only that part of the circuit will be considered which is divided into branches and each branch transmitting part of the total current; the rest of the circuit is assumed to be closed through some electric source, as, for instance, a voltaic battery.

Before applying Ohm's law to derived circuits, the word *conductivity* should be thoroughly understood. Conductivity can be defined as the facility with which a body transmits electricity, and is the opposite of resistance. For example, copper is of low resistance and high conductivity; mercury is of high resistance and low conductivity. In other words, conductivity is the inverse or reciprocal of resistance. There is no established unit of conductivity; it is used merely as a convenience in calculations. For example, if the resistance of a circuit is 2 ohms, its conductivity is represented by one-half; if the resistance is increased to 4 ohms, the conductivity would only be one-half as much as in the former case and would be represented by one-quarter.

The **conductivity** of any conductor is, therefore, unity divided by the *resistance* of that conductor; and, conversely,

the resistance of any conductor is unity divided by its conductivity.

69. Fig. 51 represents a derived circuit of 2 branches.

Let r_1 and r_2 = the separate resistances of the two branches; c_1 and c_2 = the separate currents in each branch, respectively, and C = the sum of the currents in the two branches; that is, the current in the main or undivided branch. Then, $c_1 + c_2 = C$, and $C - c_2 = c_1$.

When the current flows from a to b, if the resistances r_1 and r_2 are equal, the current will divide equally between the two branches; thus, if a current of 2 amperes is flowing in the main circuit, one ampere will flow through each branch.

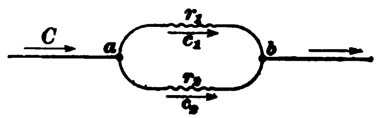


FIG. 51.

When the resistances of the two branches are unequal, the current will divide between them in inverse proportion to their respective resistances. In Fig. 51 the resistances of the two branches are r_1 and r_2. Therefore, $c_1 : c_2 :: r_2 : r_1$.

By algebra, this proportion gives the two following formulas:

For the first branch, $c_1 = \frac{C r_2}{r_1 + r_2}$. **(10.)**

That is, *of two branches in parallel, dividing from a main circuit, the current in the first branch is equal to the current in the main multiplied by the resistance of the second branch, and the product divided by the sum of the resistances of the two branches.*

For the second branch, $c_2 = \frac{C r_1}{r_1 + r_2}$. **(11.)**

Of two branches in parallel, dividing from a main circuit, the current in the second branch is equal to the current in the main multiplied by the resistance of the first branch, and the product divided by the sum of the resistances of the two branches.

EXAMPLE.—Suppose the resistance r_1 of the first branch is 2 ohms, and the resistance r_2 of the second branch is 3 ohms, find the separate currents c_1 and c_2 in the two branches, respectively, when the current C in the main or undivided branch is 60 amperes.

SOLUTION.— $r_1 = 2$ ohms, $r_2 = 3$ ohms, and $C = 60$ amperes. To find the current c_1 in the first branch, substitute these values in formula **10**, which will give $c_1 = \frac{C r_2}{r_1 + r_2} = \frac{60 \times 3}{2+3} = \frac{180}{5} = 36$ amperes. Ans.

To find the current c_2, in the second branch, substitute these values in formula **11**, which will give

$$c_2 = \frac{C r_1}{r_1 + r_2} = \frac{60 \times 2}{2+3} = \frac{120}{5} = 24 \text{ amperes. Ans.}$$

70. It is clear that two conductors in parallel will conduct an electric current more readily than one alone; that is, their *joint conductivity* is greater than either of their separate conductivities taken alone. This being the case, their resistances must follow the inverse law—viz., the joint resistance of two conductors in parallel must be *less* than either of their separate resistances taken alone.

Rule.—*If the separate resistances of two conductors are equal, their joint resistance when connected in parallel is one-half of the resistance of either conductor.*

For example, take two conductors, the separate resistance of each being 2 ohms, and connect them in parallel; their joint resistance will then be one-half their separate resistance, or 1 ohm.

71. When the separate resistances of two conductors in parallel are unequal, the determination of their joint resistance when connected in parallel involves some calculation.

In Fig. 51, the conductivities of the branches are $\frac{1}{r_1}$ and $\frac{1}{r_2}$. Hence, their joint conductivity when connected in parallel is $\frac{1}{r_1} + \frac{1}{r_2} = \frac{r_2 + r_1}{r_1 r_2}$; now, since the resistance of any conductor is the reciprocal of its conductivity, then

the *joint resistance* of the two branches in parallel is the reciprocal of their joint conductivity; or, $1 \div \frac{r_2 + r_1}{r_1 r_2} = \frac{r_1 r_2}{r_2 + r_1}$. Hence, joint resistance

$$R'' = \frac{r_1 r_2}{r_1 + r_2}. \qquad \textbf{(12.)}$$

That is, *the joint resistance of two conductors connected in parallel is equal to the product of their separate resistances divided by the sum of their separate resistances.*

EXAMPLE.—In Fig. 51, given $r_1 = 2$ ohms and $r_2 = 3$ ohms; find their joint resistance in parallel.

SOLUTION.—From formula **12**, their joint resistance $R' = \frac{r_1 r_2}{r_1 + r_2} = \frac{2 \times 3}{2 + 3} = \frac{6}{5} = 1\frac{1}{5}$ ohms. Ans.

72. Fig. 52 represents a divided circuit of three branches. Let r_1, r_2, and r_3 be the separate resistances of those branches, respectively. Then, $\frac{1}{r_1}$, $\frac{1}{r_2}$, and $\frac{1}{r_3}$ represent the separate conductivities of the three branches, respectively. Their joint conductivity $= \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3}$. Since the joint resistance is the reciprocal of their joint conductivity, then it is equal to

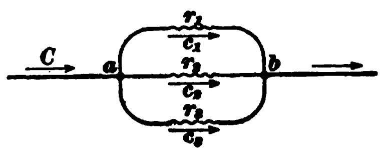


FIG. 52.

$$1 \div \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3} = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}.$$

Hence, the joint resistance of three branches in parallel

$$R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}. \qquad \textbf{(13.)}$$

That is, *the joint resistance of three or more conductors connected in parallel is equal to the reciprocal of their joint conductivity.*

EXAMPLE.—In Fig. 52, given, $r_1 = 5$ ohms; $r_2 = 10$ ohms; and $r_3 = 20$ ohms; find their joint resistance from a to b.

SOLUTION.—By formula **13,** their joint resistance

$$R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2} = \frac{5 \times 10 \times 20}{10 \times 20 + 5 \times 20 + 5 \times 10} = \frac{1,000}{350} = \frac{20}{7}$$
$= 2\frac{6}{7}$ ohms. Ans.

73. In a derived circuit of any number of branches, the difference of potential between where the branches divide and where they unite is equal to the product of the sum of the currents in the separate branches and their joint resistance in parallel, as will be apparent from consideration of Ohm's law, Art. **34.**

For example, if the currents in the three branches, Fig. 52, are 16, 8, and 4 amperes, respectively, and the joint resistance from *a* to *b* is $2\frac{6}{7}$ ohms, then the difference of potential between *a* and *b* $= (16 + 8 + 4) \times 2\frac{6}{7} = 28 \times \frac{20}{7} = 80$ volts.

74. The separate currents in the branches of a derived circuit can be determined by finding the difference of potential between where the branches divide and where they unite, and dividing the result by the separate resistance of each branch.

For example, in Fig. 52, assume that the separate resistances of the three branches are 5, 10, and 20 ohms, respectively, and that the difference of potential between *a* and *b* is 80 volts. Then, the current in the first branch is $\frac{80}{5} = 16$ amperes; in the second, $\frac{80}{10} = 8$ amperes, and in the third, $\frac{80}{20} = 4$ amperes.

75. The separate resistances of the branches of a derived circuit can be determined by finding the difference of potential between where the branches divide and where they unite, and dividing the result by the separate currents in each branch.

For example, in Fig. 52, assume the difference of potential between *a* and *b* to be 80 volts and the currents in the

separate branches to be 16, 8, and 4 amperes, respectively; then, the resistance of the first branch is $\frac{80}{16} = 5$ ohms; of the second, $\frac{80}{8} = 10$ ohms, and of the third, $\frac{80}{4} = 20$ ohms.

EXAMPLE.—Fig. 53 represents a closed circuit, part of which, from a to b, forms a derived, or shunt, circuit of three separate branches A, B, and C in parallel; r_1, r_2, and r_3 represent the separate resistance of the branches, respectively, from a to b; and R' represents the resistance of the rest of the closed circuit from b to a in the direction in which the current is supposed to be flowing, including the internal resistance of the battery K. Let $r_1 = 2$ ohms; $r_2 = 3.2$ ohms; $r_3 = 4.4$ ohms; and $R' = .8$ ohm.

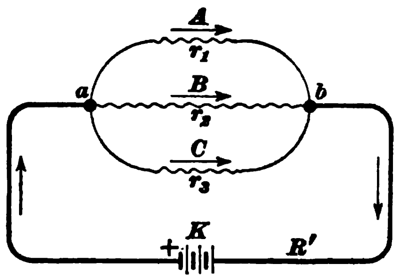


FIG. 53.

If a current of 2 amperes is flowing in the main, or undivided, circuit, find the total electromotive force developed in the battery K.

SOLUTION.—From the application of Ohm's law to closed circuits, formula **8**, $E = C R$, where E is the total electromotive force developed within the electric source, C the strength of current flowing, and R the total resistance of the circuit through which the current passes. In this particular problem, the total resistance of the closed circuit will be the *joint* resistance of the three branches in parallel, plus the resistance R' of the rest of the circuit. Hence, first find the joint resistance of th: three branches A, B, and C in parallel from a to b. By formula **13**, the joint resistance of three conductors in parallel is $\frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}$, where r_1, r_2, and r_3 represent the separate resistances of the three conductors. Substituting gives

$$\frac{2 \times 3.2 \times 4.4}{3.2 \times 4.4 + 2 \times 4.4 + 2 \times 3.2} = \frac{28.16}{14.08 + 8.8 + 6.4} = \frac{28.16}{29.28} = .9617 \text{ ohm},$$

the joint resistance of the three branches A, B, and C in parallel from a to b. The total resistance of the closed circuit is, therefore, $.9617 + .8 = 1.7617$ ohms, and $E = C \times R = 2 \times 1.7617 = 3.5234$ volts. Ans.

ELECTRICAL QUANTITY.

76. The rate of flow of liquids is expressed in units of quantity per second or minute, and similarly the strength of an electric current can be defined as a quantity of

electricity flowing per second. The practical unit of *electrical quantity* is called the **coulomb.**

The coulomb is such a quantity of electricity as will pass in one second through a circuit in which the strength of current is one ampere.

As stated in Art. **35,** the *quantity* of electricity is calculated from the strength of current; it can not be actually measured. For example, suppose the strength of current in a closed circuit to be 10 amperes, as measured by an ammeter; if such a current flows for only one second, the quantity of electricity which has passed around the circuit is 10 coulombs; but if the current flows for two seconds, the quantity of electricity would be 20 coulombs.

Hence, to calculate the quantity of electricity which has passed in a circuit in a certain time when the strength of the current in amperes is known:

Let $Q =$ the quantity of electricity in coulombs, C the strength of current in amperes, and t the time in seconds.

$$\text{Then, } Q = C\,t. \qquad \textbf{(14.)}$$

If any two of these quantities are known, the third can be readily found. By transposition, $C = \frac{Q}{t}$ and $t = \frac{Q}{C}$.

Therefore, to obtain the quantity of current which has passed through a circuit in a given time, *multiply the strength of current in amperes by the time in seconds.*

EXAMPLE.—Find the quantity of electricity in coulombs that flows around in a closed circuit in $1\frac{1}{2}$ hours when the strength of current is 12 amperes.

SOLUTION.—Reducing the time to seconds gives $1.5 \times 60 \times 60 = 5{,}400$ seconds; hence, $t = 5{,}400$ seconds and $C = 12$ amperes. Then from formula **14,** $Q = C\,t = 12 \times 5{,}400 = 64{,}800$ coulombs. Ans.

ELECTRICAL WORK.

77. When an electric current flows from a higher to a lower potential, *electrical energy* is expended and *work* is done by the current. The principle of the *conservation of energy* teaches that energy can never be destroyed; it follows,

therefore, that if energy has to be expended in forcing a quantity of electricity against a certain amount of resistance, the equivalent of that energy must be transformed into some other form. This other form is usually *heat;* that is, when a quantity of electricity flows against the resistance of a conductor, a certain amount of *electrical* energy is transformed into *heat* energy.

The actual amount of heat developed is an exact equivalent of the *work done* in overcoming the resistance of the conductor, and varies directly as that resistance. For example, take two wires, the resistance of one being twice that of the other, and send currents of equal strengths through each. The amount of heat developed in the wire of higher resistance will be twice that developed in the wire offering the lower resistance.

The unit used to express the amount of mechanical work done is known as the *foot-pound.* The work done in raising any mass through any height is found by multiplying the weight of the body lifted by the vertical height through which it is raised; similarly, the practical unit of *electrical work* is that amount accomplished when a unit quantity of electricity, *one coulomb*, flows between potentials differing by *one volt.*

The unit of electrical work is, therefore, the *volt-coulomb*, and is called the **joule.**

1 *joule* = .7373 foot-pound.

78. By means of the following formulas, we may find directly the amount of electrical work accomplished in *joules* during a given time in any circuit:

Let J = electrical work in joules;
C = current in amperes;
t = time in seconds during which the current flows;
E = potential, or E. M. F., of circuit;
R = resistance of circuit.

When the current and electromotive force are known,

$$J = C E t. \qquad \textbf{(15.)}$$

When the current and resistance are known,

$$J = C^2 R t. \qquad \textbf{(16.)}$$

When the resistance and electromotive force are known,

$$J = \frac{E^2 t}{R}. \qquad \textbf{(17.)}$$

To determine, therefore, the electrical work done in a given time, *multiply the quantity of electricity in coulombs which has passed in the circuit during that time by the loss, or drop, of potential as measured directly, or as computed from the values of the current and resistance.*

Example.—Find the amount of work done in joules when a current of 15 amperes flows for ½ an hour against a resistance of 2 ohms.

Solution.—Reducing the time to seconds gives $30 \times 60 = 1{,}800$ seconds $= t$. The current $= C = 15$ amperes, and the resistance $= 2$ ohms $= R$. Then, by formula **16,** the electrical work done

$$J = 15 \times 15 \times 2 \times 1{,}800 = 810{,}000 \text{ joules. Ans.}$$

79. When the work in joules is known, the work in foot-pounds

$$\text{F. P.} = .7373\,J. \qquad \textbf{(18.)}$$

That is, *the equivalent work done in foot-pounds is obtained by multiplying the number of joules by .7373.*

Example.—Express the work done in foot-pounds in a circuit when a current of 8 amperes flows for 2 hours between potentials differing by 10 volts.

Solution.—Reducing the time to seconds gives $2 \times 60 \times 60 = 7{,}200$ seconds $= t$. The current $= 8$ amperes $= C$, and the electromotive force $= 10$ volts $= E$. Then, by formula **15,** the electrical work done $= J = 8 \times 10 \times 7{,}200 = 576{,}000$ joules. Expressed in foot-pounds, this will be, by formula **18,**

$$\text{F. P.} = .7373 \times 576{,}000 = 424{,}684.8 \text{ foot-pounds. Ans.}$$

ELECTRICAL POWER.

80. Power, or *rate of doing work*, is found by dividing the amount of work done by the time required to do it. In mechanics, the unit of power is called the **horsepower;** in electrotechnics, the unit of power is the **watt.** It is

found by dividing the amount of electrical work done by the time required to do it.

Let $E =$ the electromotive force in volts; Q the quantity of electricity in coulombs; C the current in amperes; and W the power in watts.

By formula **15,** the amount of electrical work $J = C E t$. Then,

$$W = \frac{C E t}{t} = C E. \qquad \textbf{(19.)}$$

The power in watts is equal to the strength of current in amperes, multiplied by the electromotive force in volts.

EXAMPLE.—What is the power in watts developed in a closed circuit in which a current of 12 amperes is flowing between potentials differing by 25 volts?

SOLUTION.— $E = 25$ volts and $C = 12$ amperes. Hence, by formula **19,**

$$W = C E = 12 \times 25 = 300 \text{ watts. Ans.}$$

By taking into consideration the resistance of the circuit, the equation for determining the power in watts may be expressed in two other ways:

By derivation from formula **16,**

$$W = \frac{C^2 R t}{t} = C^2 R. \qquad \textbf{(20.)}$$

That is, *the power in watts is equal to the strength of current in amperes squared, multiplied by the resistance in ohms.*

EXAMPLE.—Find the power in watts in a closed circuit in which a current of 30 amperes is flowing against a resistance of 3 ohms.

SOLUTION.— $C = 30$ and $R = 3$. Hence, by formula **20,**

$$W = C^2 R = 30^2 \times 3 = 2{,}700 \text{ watts. Ans.}$$

By derivation from formula **17,**

$$W = \frac{E^2 t}{R t} = \frac{E^2}{R}. \qquad \textbf{(21.)}$$

That is, *the power in watts is the quotient arising from dividing the electromotive force in volts squared, by the resistance in ohms.*

EXAMPLE.—The drop of potential in a closed circuit when a current is flowing is 20 volts and the resistance is 10 ohms; what is the power in watts expended?

SOLUTION.— $E = 20$ volts and $R = 10$ ohms. Hence, by formula **21**,

$$W = \frac{E^2}{R} = \frac{20^2}{10} = 40 \text{ watts. Ans.}$$

81. One watt equals $\frac{1}{746}$ of a horsepower; or, one horsepower equals 746 watts.

If H. P. = horsepower,

$$\text{H. P.} = \frac{W}{746}. \qquad \textbf{(22.)}$$

That is, *to express the rate of doing electrical work in horsepower units, find the number of watts and divide the result by 746.*

The horsepower may also be expressed by three other equations, by expressing the watts in terms of electromotive force, current, and resistance, as obtained from formulas **19, 20, 21,** viz.:

$$\text{H. P.} = \frac{E\,C}{746}; \ \text{H. P.} = \frac{C^2 R}{746}; \text{ and H. P.} = \frac{E^2}{746\,R}.$$

EXAMPLE.—Given, current = 50 amperes and electromotive force = 250 volts; express the power directly in horsepower units.

SOLUTION.— $E = 250$ volts; $C = 50$ amperes; hence, H. P. $= \frac{E\,C}{746} = \frac{250 \times 50}{746} = 16.756$ horsepower. Ans.

EXAMPLE.—Given, strength of current = 25 amperes and resistance = 14.92 ohms; express the power directly in horsepower units.

SOLUTION.— $C = 25$ amperes; $R = 14.92$ ohms; hence,

$$\text{H. P.} = \frac{C^2 R}{746} = \frac{25^2 \times 14.92}{746} = 12.5 \text{ horsepower. Ans.}$$

EXAMPLE.—Given, electromotive force = 110 volts and resistance = 4 ohms; express the power directly in horsepower units.

SOLUTION.— $E = 110$ volts; $R = 4$ ohms; hence, H. P. $= \frac{E^2}{746\,R} = \frac{110^2}{746 \times 4} = 4.055$ horsepower. Ans.

82. To express the power in watts when the horsepower is known, use the following formula:

$$W = \text{H. P.} \times 746. \qquad \textbf{(23.)}$$

That is to say, *the power in watts is found by multiplying the horsepower by 746.*

EXAMPLE.—Express the equivalent of 4.35 horsepower in watts.

SOLUTION.— H. P. = 4.35; by formula **23**, the electrical power $W = 4.35 \times 746 = 3{,}245.1$ watts. Ans.

83. The watt is too small a unit for convenient use in expressing the output of large dynamos, so the *kilowatt* is generally used. One kilowatt is equal to 1,000 watts, or about $1\frac{1}{3}$ horsepower. For example, if a dynamo were rated at 75 kilowatts, it would have an output of 75,000 watts or, roughly, about 100 horsepower.

The *kilowatt-hour* is a unit of *work* commonly used in connection with electrical measurements. It is the amount of work done when 1 kilowatt is expended for 1 hour, or $\frac{1}{2}$ kilowatt for 2 hours, etc. The kilowatt-hours are therefore found by multiplying the average number of kilowatts by the number of hours during which the kilowatts were expended. Since 1 kilowatt = 1,000 watts, 1 kilowatt-hour = 1,000 watt-hours. Now, 1 watt expended for 1 second is equal to 1 joule; hence, 1 kilowatt-hour = $1{,}000 \times 3{,}600 = 3{,}600{,}000$ joules, or $3{,}600{,}000 \times .7373 = 2{,}654{,}280$ foot-pounds. The kilowatt-hour represents a definite amount of work, whereas the kilowatt expresses the rate at which work is done and is, therefore, a unit of power.

DYNAMOS AND MOTORS.

(PART 2.)

ELECTROMAGNETIC INDUCTION.

1. It has been shown that an electric current circulating around a coiled conductor produces lines of force which thread through the coil, entering at one end and leaving at the other. So long as the current in the coil remains at a constant strength, the lines of force have direction and position only; unless influenced by some exterior magnetic substance, they do not increase or diminish in number, or change their position relatively to the coil. Fig. 1 represents such a coil around which a current is flowing from the battery *B*.

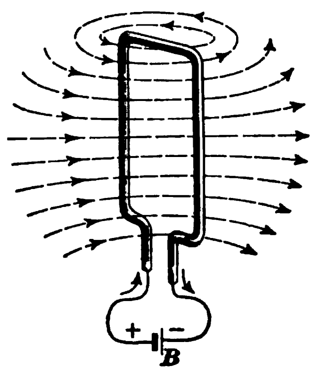


FIG. 1.

Suppose the battery is disconnected from the coil and a galvanometer for detecting small currents is inserted in its place. A magnetic pole suddenly thrown into the coil, as represented in Fig. 2, will cause a deflection of the galvanometer needle; the needle, however, will return to its original position as soon as the magnet comes to rest. Withdrawing the magnet from the coil also causes a deflection of the needle, but in the opposite direction. In the first case, a momentary current is induced in the circuit, as

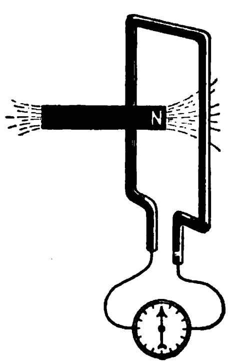


FIG. 2.

shown by the deflection of the galvanometer needle while the magnet is being inserted into the coil; this current immediately subsides when the magnet ceases to move. In the second case, the same effects are produced, with the exception that the current induced in the coil flows in an opposite direction to that in the first case.

These induced currents are caused by a change in the number of lines of force which pass through the coil. In passing into or out of the coil, the lines of force from the magnet set up an E. M. F. in that portion of the conductor in which the number of lines of force is changing, and this E. M. F. tends to send a current through the circuit.

2. In place of a small magnetic pole, imagine the coil to be suddenly inserted into a large uniform magnetic

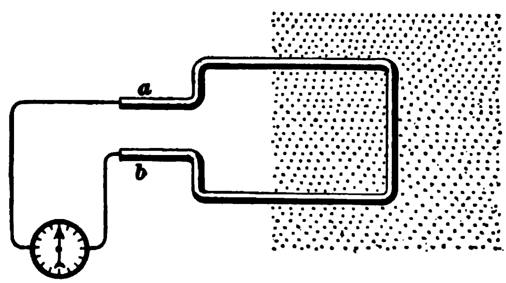


FIG. 3.

field where all the lines of force are parallel to one another. The diagram, Fig. 3, represents a cross-sectional view of such a field. The dots represent the ends of the lines of force; their direction is assumed to be downwards, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south magnetic pole. As the coil enters the magnetic field with its plane at right angles to the lines of force, a current will be induced in the coil and the galvanometer needle will be deflected; this induced current is produced by a change in the number of lines of force which pass through the coil, as in the previous case. Withdrawing the coil from the magnetic field will also induce a current in the circuit, but it will deflect the

galvanometer needle in an opposite direction, showing that the current in the circuit is reversed.

If the coiled conductor be straightened out, forming one long conductor, and then moved across the magnetic field at right angles to the lines of force, as represented in Fig. 4, a current will be generated in the circuit. The current, however, immediately subsides when the motion ceases, no matter whether the conductor is in the magnetic field or otherwise. Should the conductor be moved in the magnetic field, with its length parallel to the lines of force, as in Fig. 5, no current will be generated in the circuit. From these two experiments the following principle is deduced: *When a conductor is moved across a magnetic field so that it cuts the lines of force, an E. M. F. is generated which tends to send a current through that conductor.*

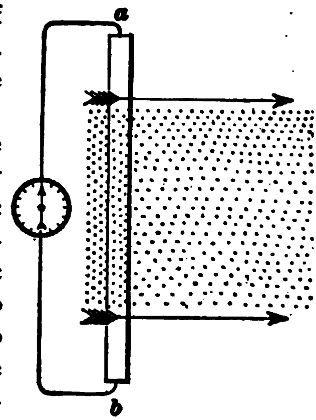


FIG. 4.

3. In reality, currents generated in a conductor *cutting* lines of force, and those *induced* in a coiled conductor by a change in the number of lines of force which pass through the coil, are due to the same movement ; for every conductor conveying an electric current forms a closed coil, and every line of force is a complete magnetic circuit by itself. Consequently, when any part of a closed coil is cutting lines of force, the lines of force are passing through the coil in a definite direction and changing at the same rate as the cutting. For example, in Fig. 6 the heavy loop *C. C.* represents a closed coil, and the light loop *L. F.* represents four

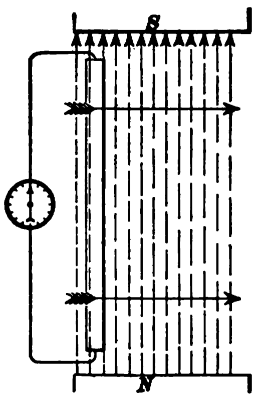


FIG. 5.

lines of force. When the two closed loops are brought together, the closed coil is cut at one place a by four lines of force, and at the same time the number of lines of force passing through the closed coil increases from nothing to four. In calculations, however, it is convenient to make a distinction between the two cases: in the one case, to consider that the current is *generated* by a conductor of a certain length *cutting* lines of force at right angles; and in the other, to consider that the current in a closed coil is *induced* by a *change* in the number of lines of force passing through the coil.

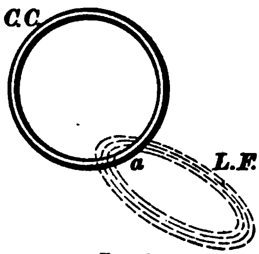


FIG. 6.

In these explanations, it must not be forgotten that an electric current is the result of a difference of potential or electromotive force. Consequently, it is not actually a current that is generated in the moving wire, but an electromotive force; for, in all of the previous experiments in which currents are induced or generated in a conductor by the lines of force, if the circuit is opened at any point, no current will flow, but the electromotive force still exists.

4. There are three methods of producing an electromotive force by induction in a coiled conductor; namely, by *electromagnetic induction*, by *self-induction*, and by *mutual induction.*

In **electromagnetic induction,** the change in the number of lines of force which pass through the coil is due to some relative movement between the coil and a magnetic field; as, for example, by thrusting a magnet into the coil or withdrawing it, or, again, by suddenly inserting the coil into a magnetic field with its plane at right angles to the lines of force.

5. In **self-induction,** the change in the number of

lines of force is caused by sudden changes in a current which is already flowing through the coil itself and is supplied from some exterior source. This exterior current produces a magnetic field in the coil, and so long as the strength of the current remains constant, there is no change in the number of lines of force which pass through the coil. But if the strength of the current is suddenly increased, a change in the number of lines of force occurs; the change in turn *induces* an electromotive force in the conductor, which *opposes* the original current in the coil and tends to keep the current from rising. Its action is similar to that which would take place if some extra resistance were suddenly inserted into the circuit at the instant the strength of the current is increased. The original current eventually reaches its maximum strength in the coil as determined by Ohm's law, but its rise is not instantaneous; it is retarded to a certain extent by this induced electromotive force. If, on the contrary, the strength of the original current is suddenly allowed to decrease, another change is produced in the lines of force which pass through the coil; this new change induces an electromotive force in the coil which acts in the *same* direction as that of the original current and tends to keep it from falling. As in the previous case, however, the original current will eventually drop to its minimum strength, as determined by Ohm's law, but it will fall gradually, and a fraction of a second will elapse before it becomes constant. In short, the current flowing through a coiled conductor acts as if possessing *inertia;* any sudden change in the strength of the current produces a corresponding electromotive force which opposes that change and tends to keep the current at a constant strength.

6. In **mutual induction,** two separate coiled conductors, one conveying a current of electricity, are placed near each other, so that the magnetic circuit produced by the one in which the current flows is enclosed by the other, as shown in Fig. 7, where the current circulates around the coil P when the circuit is closed at key b. The coil P is

called the **primary,** or **exciting, coil;** the other coil S is the **secondary coil.**

Any sudden change in the strength of the current circulating around the primary coil, as, for instance, breaking the circuit at b, produces a corresponding change in the number of lines of force in the magnetic circuit which passes through both coils, and hence an electromotive force is induced in the secondary coil.

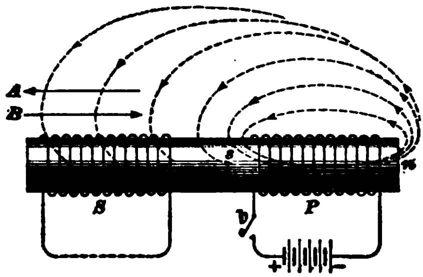


FIG. 7.

If the primary circuit is completed at b and the current tends to rise in that coil, the electromotive force induced in the secondary coil causes a current to circulate around in it in the *opposite* direction to the current in the primary coil. If, on the contrary, the circuit at b is suddenly opened and the current in the primary decreases, the induced electromotive force in the secondary causes a current to circulate around in it in the *same* direction as the current in the primary coil.

To make this clear, in Fig. 7, suppose the current in the primary coil to be suddenly established by closing the switch at b. The lines of force will surround the conductors and spread out in all directions. The lines of force spreading out in the direction of arrow A cut the conductors of the secondary coil. The resulting current in the secondary would have the same direction were the lines of force stationary, as shown, and the coil S moved along the core in the direction of arrow B. Then, according to the thumb-and-finger rule, Art. **8,** the current will flow in the secondary coil as indicated by the arrows, or opposite to that in the primary. Similar reasoning will show that when the primary circuit is broken and the lines of force collapse, the direction of the current in the secondary coil S will be the *same* as that which existed in the primary.

7. The direction of an induced current in a coil depends upon the direction of the lines of force in the coil, and whether their number is increasing or diminishing. If these two facts are known, the direction in which the current circulates around the coil is determined by the following rule:

Rule.—*If the effect of the action is to diminish the number of lines of force that pass through the coil, the current will circulate around the coil in the direction of the movement of the hands of a watch as viewed by a person looking along the magnetic field in the direction of the lines of force; but if the effect is to increase the number of lines of force that pass through the coil, the current will circulate around in the opposite direction.*

For example, in the diagram, Fig. 3, when the coil is inserted into the magnetic field, thereby *increasing* the number of lines of force which pass through the coil, the current circulates from *b* around the coil to *a*, and thence through the galvanometer to *b* again; when the coil is withdrawn and the number of lines *diminishes*, the current circulates in the opposite direction, that is, from *a* around the coil to *b*, and thence through the galvanometer to *a* again. That end of the coiled conductor *from* which the current flows *to* the external circuit, as from *a* through the galvanometer, in the first case, is the *positive* pole or terminal of the coil; in the second case. *b* is the *positive* pole or terminal.

8. Referring to the straight conductor in which a current is generated by moving it across a magnetic field at right angles to the lines of force, the direction of the current in the conductor depends upon the relation of the direction of the lines of force to that of the moving conductor. The conductor must necessarily be moved across the magnetic field at some angle to the lines of force, and the current generated in the conductor will tend to flow at right angles to the lines of force and at right angles to the direction in which the conductor is moving. In Fig. 4, if the conductor

is moved from left to right across the lines of force, the current generated in it will tend to flow upwards through the conductor; that is, from b to a through the conductor, then from a to b through the galvanometer. If the conductor is moved in the opposite direction, that is, from right to left, the current in the conductor will tend to flow in a reversed direction, that is, from a to b through the conductor and from b to a through the galvanometer. A convenient method for remembering the direction of a current generated in a straight conductor, when the conductor is moved in a magnetic field at right angles to the lines of force, is as follows:

Rule.—*Place thumb, forefinger, and middle finger of the right hand so that each will be perpendicular to the other two; if the forefinger points in the direction of the lines of force and the thumb points in the direction towards which the conductor is moving, then the middle finger will point in the direction towards which the current generated in the conductor tends to flow.*

For example, in Fig. 8, if a vertical conductor be moved across the front of the north pole N of the magnet in the direction towards which the thumb points, the current generated in the conductor will flow downwards, that is, in the direction towards which the middle finger is pointing.

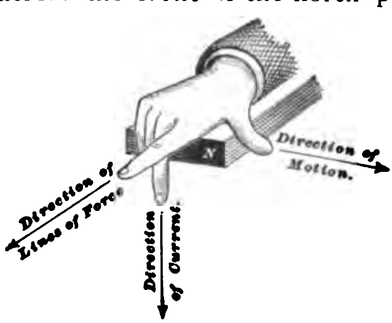


FIG. 8.

The summary of these electromagnetic induction experiments can be stated as follows: *Electromotive forces are generated in a conductor moving in a magnetic field at right angles to the direction of the lines of force, or are induced in a coiled conductor when a change occurs in the number of lines of force which pass through the coil.*

PHYSICAL THEORY OF THE DYNAMO.

9. In Fig. 9, a rectangular coil of copper wire is placed in the center of a uniform field with its plane lying perpendicular to the lines of force; in this position, the coil encloses the greatest number of lines of force. A voltmeter *V. M.* for measuring small E. M. F.'s is connected to the two ends of the coil, as shown in the diagram. The circuit in the voltmeter is kept closed, and any E. M. F. generated in the conductor will be indicated by the deflection of the index needle. So long as the coil remains at rest in the magnetic field no E. M. F. is generated; but imagine the coil to be rotated on an axis in its own plane, such as represented by the broken line *m n*, in the direction indicated by the curved arrows. As the coil starts to rotate, its sides *c d* and *e f* begin to cut the lines of force at right angles, thus generating an E. M. F. in each side. From the rule stated in Art. **8**, the E. M. F. generated in the upper side tends to cause a current to flow from *f* to *e*; and in the lower side, the current tends to flow from *d* to *c*. Hence, the E. M. F.'s generated in the two coils are added together, and the total E. M. F. generated by the coil is indicated by the *V. M.* between *a* and *b*, the end *b* forming the *positive* terminal of the coil. If the coil is rotated at a uniform angular velocity, that is, if the speed of rotation is constant throughout each revolution, the deflection of the voltmeter becomes greater as the coil revolves from its vertical position until it passes through one-quarter of a revolution and reaches a position where its plane lies parallel to the lines of force.

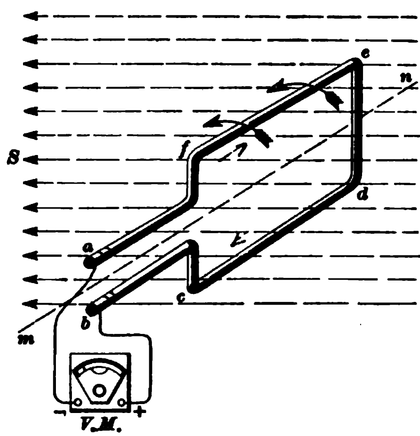


FIG. 9.

10. The diagram, Fig. 10, represents an end view of the coil in two positions: position *1*, as shown by the dotted lines, represents the coil standing vertically at the moment of starting, and position *2*, as shown by the full lines, represents the coil lying horizontally after passing through one-quarter of a revolution. The deflection of the needle, if read at frequent intervals during this quarter of a revolution, gradu-

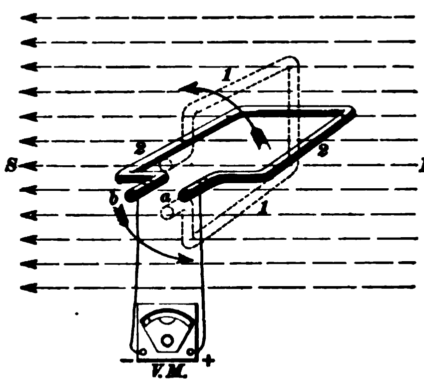


FIG. 10.

ally increases, beginning at zero in position *1*, and reaching a maximum at position *2*. The gradual rise of the E. M. F. in the circuit while the coil is revolving from position *1* to position *2* can be graphically shown by means of cross-section paper, Fig. 11. The horizontal divisions represent equal intervals of time, and the sum of the divisions between *A* and *B* is the total time occupied by the coil in revolving one-quarter of a revolution; the vertical divisions represent E. M. F., and the sum of the divisions between *A* and *Y* is the total E. M. F. that is being generated in the coil when it is passing through position *2*. The vertical distances between the line *A B* and the curved line represent the E. M. F. which is being generated in the coil at every instant

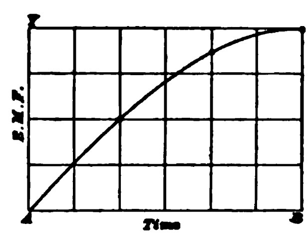


FIG. 11.

during its rotation between positions *1* and *2*. For example, let each vertical division represent 2.5 volts; then, the distance between *A* and *Y* represents 10 volts. When the coil has revolved one-third of the distance between positions *1* and *2*, Fig. 10, it has consumed one-third of the time; hence, at this instant the E. M. F. that is being generated

in the coil is represented by the number of divisions between the line *A B* and the curved line, at one-third the distance towards *B*, which equals two divisions; or $2 \times 2.5 = 5$ volts. When the coil travels two-thirds the distance between positions *1* and *2*, the E. M. F. that is being generated at that instant is represented by the number of divisions between the line *A B* and the curved line at two-thirds the distance towards *B*, which equals about 3.48 divisions, or $3.48 \times 2.5 = 8.7$ volts.

11. After the coil passes through position *2*, the E. M. F. that is being generated begins to diminish, and by the time the coil has revolved one-half of a revolution and is once more in a vertical position, the E. M. F. falls to zero again. The E. M. F. that is being generated at every instant during one-half of a revolution can be shown by a continuation of the curve on cross-section paper, Fig. 12. The sum of the divisions between *A* and *C* represents the total time occupied by the coil in rotating one-half of a revolution. It will be seen that the maximum E. M. F. that is being generated at any instant is at position *2*, Fig. 10, which corresponds to *B*, Fig. 12. In this position the plane of the coil lies parallel to the lines of force, and its

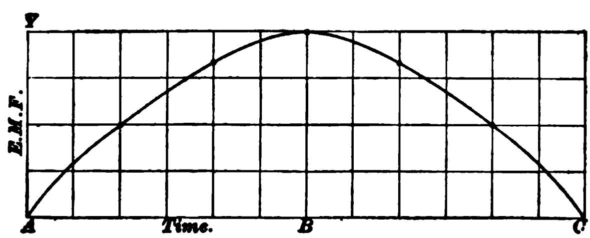


FIG. 12.

sides, corresponding to *c d* and *e f*, Fig. 9, are cutting the lines of force at exactly right angles. The sides of the coil at the moment of passing through this position are cutting more lines of force for equal intervals of time than in any other position during the first half of a revolution.

From this fact the following principle is deduced: *The E. M. F. generated in a moving conductor cutting lines of*

force at right angles is directly proportional to the rate of cutting. Suppose, for example, that a magnetic field contains 100,000 lines of force, and that a conductor is moved across the field at right angles in such manner as to cut every line of force. If the time occupied by the conductor in passing across the field is one second, then the rate of cutting is 100,000 lines per second; or, if it occupied two seconds, the rate of cutting is 50,000 lines per second, and so on. The E. M. F. generated in the former case is twice as great as that generated in the latter. The method for determining the number of lines of force in a magnetic field will be described later.

12. Fig. 13 shows the coil after being rotated one half of a revolution. As soon as the coil starts on the last half of the revolution, its sides *c d* and *e f* cut a few lines of force, and, consequently, an E. M. F. is generated in each side. The E. M. F., however, tends to cause a current to flow in the coil in an opposite direction to that which tends to flow during the first half of the revolution. For, by applying the rule in Art. **8**, the E. M. F. generated in the sides tends to cause a current to flow from *c* to *d* and from *e* to *f*; the end *a* of the coil, which in the first half of the revolution was the negative terminal of the coil, now forms the positive terminal. Hence, in order to allow the current to enter the positive binding-post of the voltmeter, the connections must be reversed.

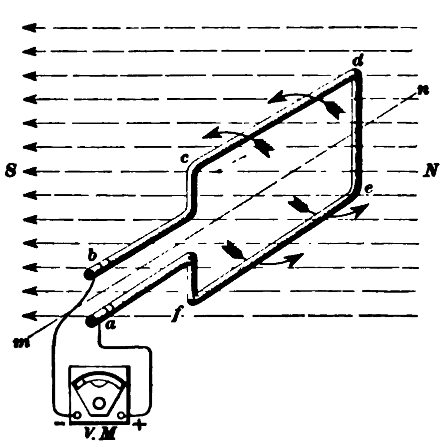


FIG. 13.

The E. M. F. that is generated as the coil is rotated through the last half of

the revolution gradually rises as in the first half, reaching a maximum height when the plane of the coil lies parallel to the lines of force, and afterwards falling to zero again as the

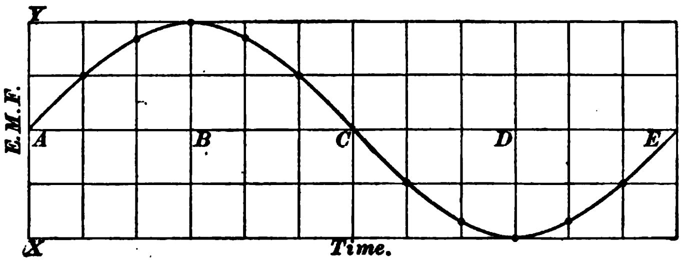


FIG. 14.

coil reaches a vertical position. In Fig. 14, the E. M. F. that is generated in the coil at every instant during one complete revolution is graphically shown by the use of the cross-section paper. The sum of the divisions between A and E represents the time occupied by the coil in making one complete revolution; the divisions between A and Y represent the E. M. F. which tends to send a current in one direction through the coil as in the first half of the revolution, and the divisions between A and X represent the E. M. F. which tends to send a current through the coil in an opposite direction as in the last half of the revolution. The divisions between the curved line and the line A E, or **base line,** give the E. M. F. that is being generated in the coil at any instant during the revolution, and the direction in which the E. M. F. tends to act depends upon whether this E. M. F. falls above or below the base line A E. For convenience, let the direction in which the E. M. F. tends to act in the first half of the revolution be called the **positive** (+) **direction,** and in the last half the **negative** (−) **direction.** For example, the E. M. F. that is generated in the coil when it has revolved three-quarters of a revolution is represented by the distance between D and the curved line, which, in this case, is two divisions; and since these divisions are below the base line, the direction in which this E. M. F. tends to act is negative.

13. In Fig. 15, instead of connecting the external circuit directly to the ends of the coil, suppose the wires *o* and *p* to be brought to two brushes *r* and *s*, which lie in a

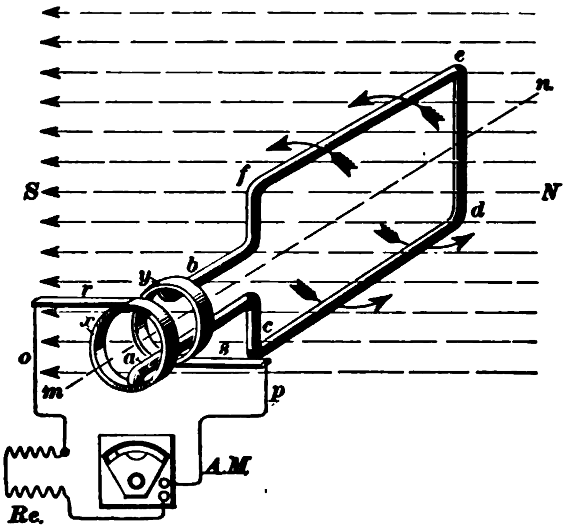


FIG. 15.

horizontal position and bear on the two *collector rings* *x* and *y*, respectively. These collector rings, it will be seen, are connected to the two ends of the coil; *x* to *a* and *y* to *b*.

The resistance of the entire circuit, including the coil, ammeter, collector rings, and brushes, is comparatively small; hence, any E. M. F. generated in the coil causes a corresponding current to flow through the circuit, and its strength is indicated by the ammeter *A. M.* When the coil begins to revolve, a feeble E. M. F. is generated in it as previously described. This E. M. F. causes a corresponding current to flow through the circuit in a positive direction; as the E. M. F. becomes larger, the strength of current in the circuit becomes greater, and *vice versa.* After the coil is rotated one half of a revolution, and the direction in which the E. M. F. tends to act becomes negative, the direction of the current in the circuit is also reversed. If

there is no self-induction to retard the rise and fall of the current in the circuit, as explained in Art. **5**, the strength of the current in the circuit at any instant is exactly proportional to the E. M. F. that is being generated in the coil at that moment; for, according to Ohm's law, the strength of current in any circuit is equal to the E. M. F. generated in that circuit, divided by its resistance. The rising and falling and also the reversing of the current in all parts of the circuit for each revolution, therefore, can be represented graphically on cross-section paper in the same manner as previously described for the E. M. F. Fig. 16

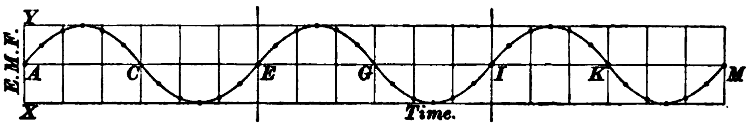


FIG. 16.

represents the rising, falling, and reversing of the current in the circuit for three complete and consecutive revolutions of the coil; the divisions between *A* and *E*, *E* and *I*, and *I* and *M* represent the time of each revolution, respectively. The divisions between the base line *A M* and the curved line above the base line represent the strength of current in the circuit when the direction of flow is positive, and those below represent the strength of current when the direction of flow is negative. Revolving the coil, therefore, at a constant speed generates a current in the circuit, which, in every complete revolution, rises gradually to a maximum strength and falls to zero in one direction, then is reversed, and the same effect is produced in the opposite direction. In other words, the current in the circuit *alternates* from one direction to the opposite direction in each revolution.

An electric current of this character flowing through a circuit is termed an **alternating current.**

14. The next step is to demonstrate the principle of changing, or *commuting*, this alternating current into a *continuous*, or *direct*, current; that is, a current which always

flows in the same direction through the external circuit. In Fig. 17, the two ends of the coil are fastened to two halves s and s' of a metallic tube. These halves are called **segments,** and in this case are separated by a small air-space, the rigidity of the coil holding them apart. The combination of the two segments, or, in fact, any number

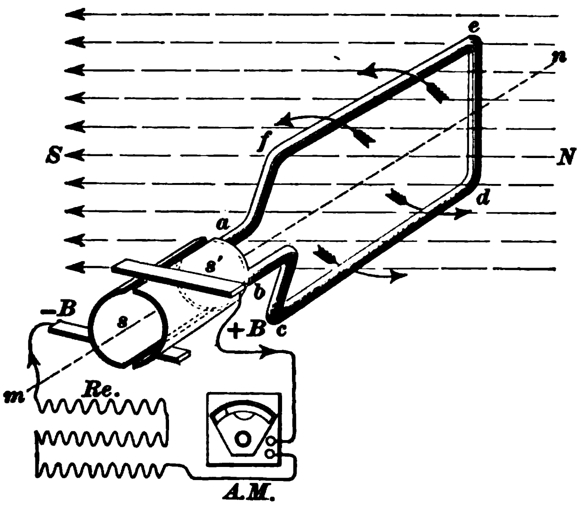


FIG. 17.

of segments held together in this position, is called the **commutator.** Two copper strips $+B$ and $-B$, called **brushes,** press against the segments, and are held in a horizontal position while the coil is rotated. The brushes rub, or *brush*, against the segments and make electrical contact only.

When the coil is in a vertical position, as represented in the figure, both brushes rest against both segments; but as soon as the coil starts on the first half of a revolution in the direction indicated by the arrows, the brush $-B$ leaves segment s', and rubs only against segment s; brush $+B$ leaves segment s, and rubs only against segment s'. As previously described, the electromotive force that is generated in the coil during the first half of a revolution causes a current to

flow from *a* through the coil to *b*, and from *b* through the external circuit to *a* again, making *b* the positive end of the coil. Hence, in this case, $+B$ is the positive brush, and the current in the external circuit flows in the direction indicated by the arrow-heads. As the coil starts on the last half of a revolution, the direction of the current in the coil changes, and *a* becomes the positive end of the coil. But the current in the external circuit continues to flow in the same direction as in the first half of the revolution, and $+B$ remains the positive brush. For, at the beginning of the second half of a revolution, when end *a* of the coil becomes positive, $-B$ leaves segment *s* and makes contact with *s'*, and $+B$ leaves *s'* and makes contact with *s*. Hence, the current in the external circuit, during a complete revolution, flows from the positive brush $+B$ through the ammeter *A. M.* and the resistance *Re* to the negative brush $-B$; that is, the current in the external circuit flows continually in the same direction, while the current in the coil itself flows in two directions during every revolution. But the strength of the current in the external circuit is by no means constant; it rises from zero to a maximum strength, and falls again to zero twice in every revolution, but always in the same direction. The effect is graphically shown in Fig. 18 by the use

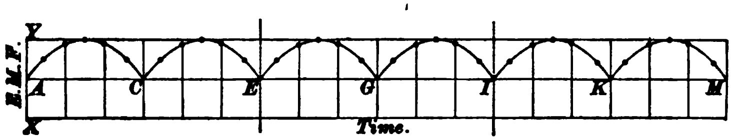


FIG. 18.

of cross-section paper, where the divisions between *A* and *E*, *E* and *I*, and *I* and *M* represent the time occupied by the coil in rotating each revolution, respectively, and the vertical divisions between the base line *A M* and the curved line represent the strength of the current in the external circuit at every instant during the three revolutions. The effect is produced continually in the external circuit if the coil is rotated at a constant speed. These impulses in the strength of the current give it the name of **pulsating** current.

A consideration of the preceding paragraphs will show the student that direct-current dynamos require commutators, while alternating-current dynamos employ only collector rings.

15. In Fig. 19, two separate coils are placed in a magnetic field at right angles to each other. Four metallic

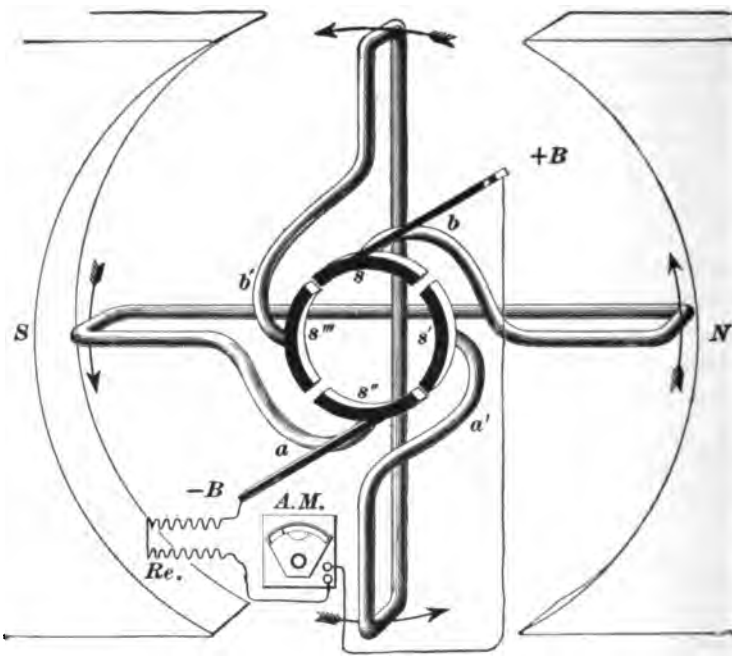


FIG. 19.

segments s, s', s'', and s''' are cut from a cylindrical ring to form the commutator, and are separated from one another by small air-spaces; the two ends of each coil are connected to two opposite segments in such manner that an imaginary diameter connecting the two segments together would lie at right angles to the plane of their coil, as shown in the figure. Two metallic brushes $+B$ and $-B$ rub against the commutator, touching the two segments diametrically opposite to each other. A line drawn through the center of the

commutator, connecting the contact ends of the two brushes, should lie at right angles to the direction of the lines of force in the magnetic field in which the coils are rotated. As the two coils and commutator are rotated in the direction indicated by the arrows, the two brushes rub against the segments consecutively and always make contact with the two opposite ones. The brushes are connected to an external circuit consisting of the ammeter *A. M.* and the resistance *Re.* At the position of the coils in the figure, the brushes are rubbing against the segments s and s'', which are connected to the ends of the horizontal coil. From previous experiments, it will be seen that at this position the horizontal coil is generating a maximum E. M. F., which tends to send a current from a through the coil to b; hence, the current is flowing in the external circuit from $+B$ to $-B$. After the coils and commutator are rotated one-eighth of a revolution from this position, and the E. M. F. in the coil begins to fall, the brush $+B$ passes from segment s to segment s', and brush $-B$ passes from s'' to s'''. The E. M. F. that is being generated in the vertical coil when the brushes pass to segments s' and s''' is nearly maximum. Consequently, the strength of the current which has been flowing in the external circuit from the other coil does not decrease to zero; it only diminishes a small amount before the segments of the next coil make contact with the brushes, when it begins to increase again. It will be seen that during one complete revolution of the moving parts, the brushes passed over four segments; that the direction of the current produced is *from* the coils *to* brush $+B$, and *into* them *from* brush $-B$. These actions produce a *direct* current in the external circuit which flows continually in the same direction, but whose strength fluctuates, or changes, regularly four times in every revolution.

By resorting again to the cross-section paper, the fluctuations of the current in the exterior circuit can be graphically shown. In Fig. 20, the divisions between the base line *A M* represent the strength of current in the external circuit for three complete revolutions. So long as the speed

of rotation is uniform, the current decreases to a little less than three-quarters of its maximum strength, providing, of

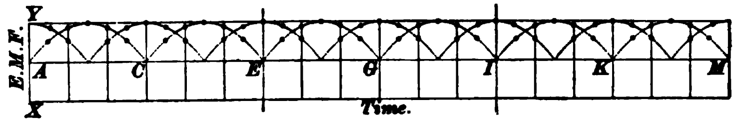


FIG. 20.

course, the resistance of the external circuit is not altered; the dotted curved lines indicate how the strength of the current would fall to zero if only one of the coils were used.

The strength of such currents can be made more uniform and the pulsations less noticeable by using several coils connected to the segments of a commutator, the planes of the coils being placed at equal angles from each other. A continuous current of uniform strength is known as a constant current.

16. In Art. **30,** Part 1, it is stated that the *permeability* of iron is much greater than that of air; or, in other words, if a piece of iron were inserted in a magnetic field, the number of lines of force in the field would be greatly increased. Hence, if the coils are wound around a cylindrical drum of iron, as shown in Fig. 21, the number of lines of force passing through the coils is increased, and the E. M. F. that is generated is greater, since, Art. **11,** the E. M. F. is proportional to the rate of cutting of the lines of force. The coils are entirely insulated from the iron core by some non-conducting material, such as cloth, mica, or paper; otherwise, they would be short-circuited on the core; that is, the current would flow through the

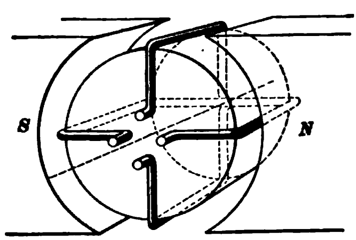


FIG. 21.

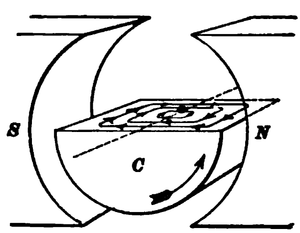


FIG. 22.

iron instead of passing into the external circuit. The other conditions remain unchanged; i. e., the lines of force have the same direction as in the previous cases, and remain in one position while the coils are revolved. The core should not be made of one solid mass of iron; for, if such were the case, the core, when rotated, would act as a large closed conductor, cutting lines of force at right angles. The E. M. F. generated in the core would cause **local,** or **eddy,** currents to flow through the iron itself, heating it and uselessly dissipating a large amount of energy. An idea of how these eddy currents would circulate in a solid iron core can be formed from Fig. 22. *C* represents the solid iron core, the top half of which is cut away. The curved lines and arrow-heads show the direction in which the eddy currents would flow if the core was rotated in the direction indicated by the large arrow. To overcome this difficulty, the core is made of a large number of round, thin iron plates, or disks, each disk being insulated from the adjacent ones by some non-conducting material, such as tissue-paper, insulating japan, or simply by the oxide formed on the surface of the disk during the process of its manufacture. The disks should be fastened together in such a manner that, when rotated in a magnetic field, their flat surfaces are parallel to the direction of the lines of force and to the direction of rotation, as shown by Fig. 23. Dividing the core into disks in no way diminishes the magnetic permeability of the iron, and for all practical purposes, it prevents the eddy currents from flowing. A core made in this way is said to be **laminated.**

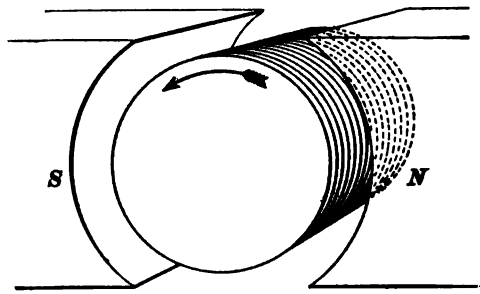


FIG. 23.

17. Iron cores are generally made in two styles: **drum** or **ring.**

A drum core may be defined as a laminated cylinder, the length being generally greater than the diameter, such as shown in Fig. 23.

A ring core may be defined as a laminated rim of rectangular cross-section, such as *R* in Fig. 24.

An iron core inserted between the poles of a magnet not only increases the total number of lines of force from the magnet, but attracts nearly all the stray lines of force from the surrounding air; that is, the lines of force prefer to complete their circuit through iron rather than through air or other non-magnetic substances. For example, in Fig. 24, an iron ring *R* is placed between the poles *N* and *S* of

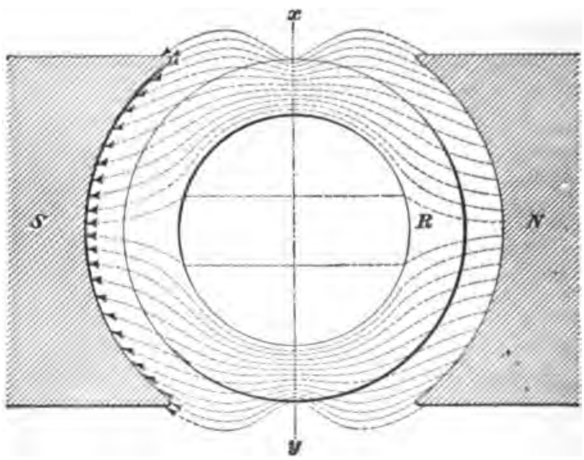


FIG. 24.

a magnet; the lines of force pass out from the north pole *N* and enter the iron ring. When passing across the air-gap, they are uniformly distributed, but after entering the ring, they crowd together and remain in the iron as long as possible. If the total number of the lines of force is large in comparison with the cross-sectional area of the iron ring on *xy*, a few will pass through the air in the inside of the ring, as shown in the cut; but in most cases the number of such stray lines is not large enough to be considered. Consequently, in Fig. 25, if a loop of insulated wire *a b c d* is

wound around the iron ring, and the ring and loop are rotated on a central axis *m n* like the rim of a fly-wheel, only that part of the loop from *a* to *b* is cutting lines of force; the rest of the loop, from *b* to *c* and from *c* to *d*, is inactive in relation to the lines of force. From the rule

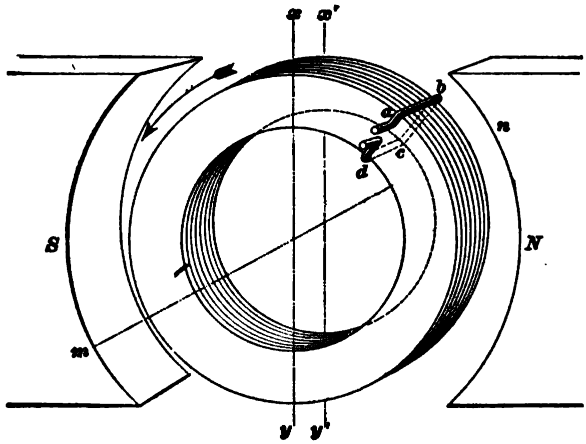


FIG. 25.

given in Art. **8**, it will be seen that the E. M. F. generated in the side *a b* of the loop tends to send a current from *b* to *a* during the first half of the revolution from $y\,y'$ to $x\,x'$, and in the opposite direction during the last half.

18. No current will flow from the loop through the external circuit when the ring is made of some non-magnetic substance, as will be understood from the following explanation: Imagine the iron ring to be moved from the field without disturbing the loop; then, imagine the loop to be rotated around the axis *m n* in precisely the same path as before. The lines of force in the field are now uniformly distributed, and as the loop moves, the part between *c* and *d* will cut the lines of force at approximately the same rate as the part between *a* and *b*. But the electromotive forces generated in the two parts tend to oppose each other; that is, the E. M. F. generated between *a* and *b* tends to act

away from *b*, and that generated between *c* and *d* tends to act away from *c*. Hence, there is no difference of potential between the ends *a* and *d*, and no current will flow through an external circuit.

After replacing the iron ring again, suppose the insulated wire to be wound around it several times, as represented in

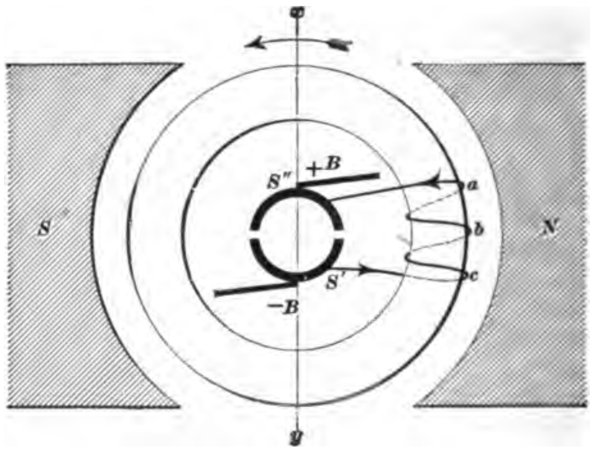


FIG. 26.

Fig. 26, and the ends of the coil connected to two metallic segments S' and S''. By applying the rule in Art. **8**, it will be seen that the electromotive forces generated in the separate turns at *a*, *b*, and *c* are added together; that is, the difference of potential between the brushes $+B$ and $-B$ is the sum of the electromotive forces generated in the separate turns. The current obtained from such a coil is *pulsating*, and is similar to that described in Art. **14.** For all practical purposes, the total E. M. F. generated by such a coil is directly proportional to the number of turns. For example, if a coil of one turn generates two volts at a certain position and angular velocity, then a coil of 4 turns will generate 8 volts under the same conditions, and so on. But the turns in each coil must be approximately close together. For, if the coil is wound over a large portion of the ring, some of the turns, at one position

of the coil, will be cutting the lines of force as they pass out from the north pole, while other turns will be cutting the lines of force as they enter the south pole, the electromotive forces generated in the two cases being opposed to each other. This action will be readily understood by winding the entire core with one large coil of several turns and connecting the two ends of the coil together, as represented in Fig. 27. This is known as a *ring* winding, or one in which the conductors are wound in the form of a helix

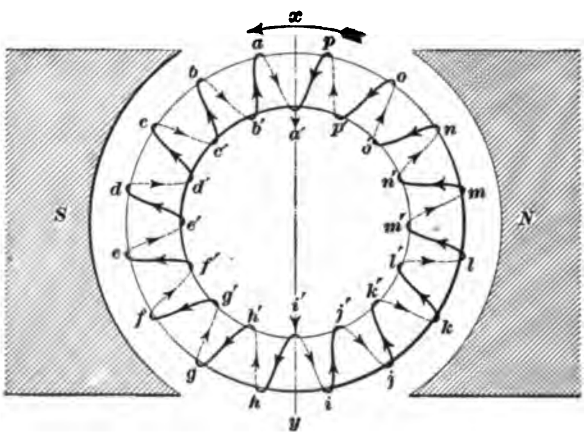


FIG. 27.

on a ring core. At the instant the ring and coils reach the position shown in the figure, the E. M. F. generated in the separate turns tends to act in the direction indicated by the arrow-heads upon the winding. No current can flow around the coil, because the electromotive forces generated in the two halves act towards each other at *a'*, and away from each other at *i'*.

19. It is possible, however, to obtain a continuous current from the coil by the addition of a commutator with several segments, as will presently be seen. If the ends of a voltmeter are touched to *a'* and *i'* during the instant the coil occupies the position in Fig. 27, a difference of potential between the two points will be indicated, *a'* being the

positive point and i' the negative. Hence, if these two points are connected to an external circuit, a current will flow through it from a' to i', while the coil is at the position shown in the figure. As soon, however, as the coil is rotated about one-sixteenth of a revolution, the difference of potential between a' and i' will begin to fall, and the greatest difference will now be found between p' and h'. About another sixteenth of a revolution will bring the greatest difference of potential between o' and g', and so on. In short, as the coil is rotated, the greatest difference of potential will always be found between any two turns situated diametrically opposite one another when they pass through the vertical diameter $x\,y$. The next operation is to provide some means to utilize this difference of potential between each pair of turns as they arrive in a vertical position. This is accomplished by connecting each turn to a separate segment of a commutator by a small conductor, and

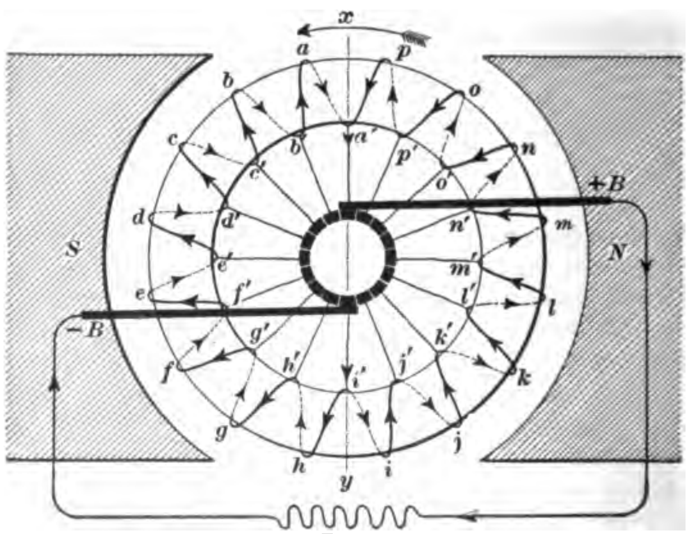


FIG. 28

allowing two brushes to rub against the commutator at two points diametrically opposite each other on the vertical

diameter $x\,y$, Fig. 28. From an examination of the figure, it will be seen that the two halves of the coil are connected in parallel or multiple; that is, the current divides at i', one half passing through the turns i, j, k, l, etc., and the other through h, g, f, e, etc. to a', where it again unites. The maximum E. M. F. that is obtained from the coil is equal, therefore, to the E. M. F. generated in one half of the coil. This statement will be better understood by comparing the coil to a battery of voltaic cells connected in multiple-series. For example, in Fig. 29, the separate cells from a to h, inclusive, correspond to the separate turns on one half of the coil, and the cells from i to p correspond to the turns on the other half. From Art. **56**, Part 1, the total E. M. F. of the above battery is equal to the E. M. F. of either of the two sets which are connected in parallel; and the total E. M. F. of either of the two sets is the product of the E. M. F. of 1 cell and the number of cells which are connected in series, as from a to h, inclusive.

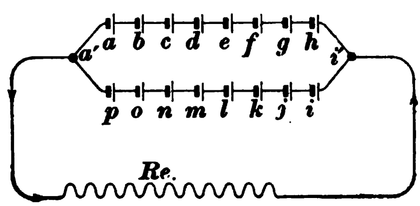


FIG. 29.

If a comparatively large number of turns and segments is used, the current flowing from $+B$, Fig. 28, through the external circuit to $-B$ will be practically continuous, that is, non-pulsating; the fluctuations caused by the brushes when passing from one segment to another are extremely minute, and produce no appreciable change in the strength of the current in the external circuit.

20. A conductor wound upon a core in the manner shown in Figs. 27 and 28 is termed a **closed-coil winding,** since all the turns are connected together in one *continuous*, or *closed*, coil, and the current is obtained from it by tapping into each turn or set of turns. In the case where the turns or sets of turns are separate and distinct from each other and their ends are connected to opposite segments of a

commutator, as in Figs. 19 and 26, the winding is termed an **open-coil** winding.

21. A *closed-coil winding* can be applied to a cylindrical drum core as described in Art. **16,** and a continuous non-pulsating current obtained from the brushes, as in the case of the ring core. The method of winding is somewhat

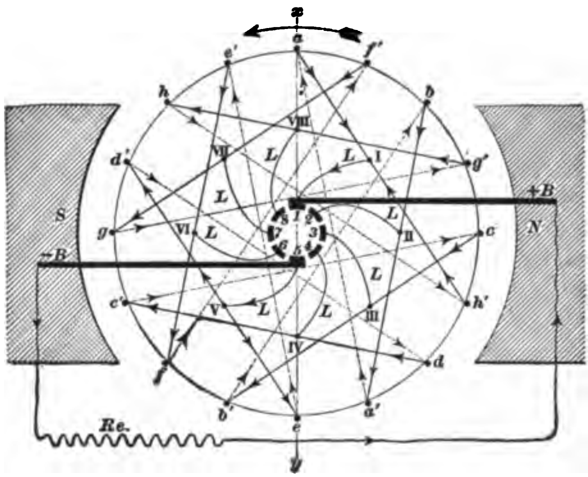


FIG. 30.

similar to that of the ring, and each turn or set of turns is tapped into and connected to the segment of a commutator by a separate lead, as will be seen from the diagram, Fig. 30. This is known as a drum winding, or one in which the conductors are wound longitudinally upon the surface of a drum core. A drum winding may also be applied to a ring core, as will be seen. The conductor is started at any convenient place on the core, as, for example, at *a*, and wound across the face of the drum to the rear end; then, wound nearly diametrically across the end, and from there along the face of the core to the front end at *a'*. From *a'*, the conductor is wound across the front end to a point somewhat in advance or behind the original starting-point *a*, as, for example, to *b*; from *b* it makes another complete turn

in like manner, which is followed by a third, and so on, until the last turn is connected to the first by joining the two ends of the coil together at *a*. A separate lead *L* is tapped into the conductor at every complete turn where it is wound across the front end of the core and connected to the separate segments of a commutator. From an examination of the diagram, it will be seen that only a part of the wires on the face of the drum are cutting the lines of force as they enter and pass out of the core at any one instant during a revolution. At the position represented, the wires *e′*, *a*, *f′* and *b′*, *e*, *a′* are the inactive ones, so far as the lines of force are concerned; but they still perform the important function of completing the circuit for the current. The parts of the core where the wires are not cutting the lines of force as the core is rotated are called the **neutral spaces**; and the two opposite parts of the commutator to which the coils are connected are called the **neutral points** of the commutator. Each individual wire becomes inactive twice during every revolution and passes through two neutral spaces; but this fact does not change the positions of the neutral spaces—they lie on an imaginary diameter approximately perpendicular to the lines of force. This same effect takes place in the commutator, i. e., each segment passes through two neutral points during one complete revolution, but the neutral points remain in a fixed position relative to the neutral spaces of the core. The neutral segments of the commutator, at any instant during a revolution, are those segments which are connected to the wires passing through the two neutral spaces at that instant. The neutral points, however, can be shifted to different points around the commutator by changing the leads from the coil to the segments. For example, in Fig. 30, the two neutral points lie opposite each other on the commutator along the vertical diameter *x y*. But if the lead from *I* is connected to segment No. *7*, instead of No. *1*, and the lead from *II* to segment No. *8*, and so on around the commutator, then the two neutral points will lie opposite each other on the commutator along a horizontal diameter, and in order to collect

any current from the commutator, the brushes $+B$ and $-B$ must be shifted around a quarter of a revolution to these new neutral points.

The current flowing through the winding divides at one neutral space and flows through the coil in opposite directions, uniting again at the other neutral space as indicated by the arrow-heads. According to the rule given in Art. **8**, the current in all the active wires in front of the north pole flows along the periphery of the core towards the observer; that in the wires in front of the south pole flows away from the observer.

22. The next step is to determine the magnitude of the E. M. F. in volts generated in a closed coil. As previously stated, the E. M. F. generated in a conductor cutting lines of force at right angles is proportional to the *rate of cutting*. Consider the case of a single conductor moving across a magnetic field in which the total number of lines of force is known; the rate of cutting is equal to the total number of lines of force cut by the conductor, divided by the time required to cut them. This may be expressed in the form of an equation: thus, *rate of cutting* $= \frac{N}{t}$, where N is the total number of lines cut and t is the time required to cut them. By definition, *one volt* is that E. M. F. generated in a conductor when it is cutting lines of force at the rate of one hundred million (100,000,000) per second. Hence, $E = \frac{N}{10^8 t}$, where E is the E. M. F. in volts and t the time in seconds, since $100{,}000{,}000 = 10^8$.

For example, suppose a magnetic field contains 4,500,000 lines of force, and a conductor cuts the total number in the same direction in 1.5 seconds. The E. M. F. that is being generated in the conductor is equal to .03 volt, since $E = \frac{N}{10^8 t} = \frac{4{,}500{,}000}{100{,}000{,}000 \times 1.5} = .03$ volt.

When two or more conductors are cutting lines of force

at equal rates, the E. M. F. obtained by connecting them in series is equal to the E. M. F. developed by one conductor multiplied by the number of conductors. Consequently, if S is the number of conductors in series, then $E = \frac{N S}{10^8 t}$, where E is the total E. M. F. in volts that can be obtained from S conductors cutting N lines in t seconds. For example, if 8 conductors are moved across the magnetic field containing 4,500,000 lines of force in 1.5 seconds, and they are connected in series, then $E = \frac{N S}{10^8 t} = \frac{4,500,000 \times 8}{100,000,000 \times 1.5} =$ .24 volt.

Next, imagine these eight conductors to be moved across the magnetic field in the same direction at the rate of 30 times per second for 1.5 seconds; then, the number of lines cut in one second is $4,500,000 \times 30 = 135,000,000$, and the total number of lines cut in 1.5 seconds is, therefore, $135,000,000 \times 1.5 = 202,500,000$. Hence, $E = \frac{(N n t) S}{10^8 t} =$

$$\frac{202,500,000 \times 8}{100,000,000 \times 1.5} = 10.8 \text{ volts.}$$

Here n = the number of times per second that one conductor cuts the lines of force.

But, in general, the E. M. F. that is obtained from several conductors connected in series moving continually across the same magnetic field at a constant number of times per second is independent of the length of time the operation is continued. For, in the above equation, $E = \frac{(N n t) S}{10^8 t}$, the two t's cancel one another, leaving the equation, $E = \frac{N S n}{10^8}$. In the above example, for instance, so long as the eight conductors are moved across the magnetic field at the rate of 30 times per second, the E. M. F. generated in them is always 10.8 volts, no matter whether the operation is continued for 1.5 seconds or for one hour. The time of 1.5 seconds was used merely to make the demonstration clearer by using a specific value for t.

23. The equation $E = \frac{NSn}{10^8}$ can now be applied with some modifications to the closed-coil conductor wound upon either the ring or drum core. The ring core, Fig. 28, will first be considered. In the equation, E is the maximum E. M. F. in volts that is obtained from the brushes $+B$ and $-B$ when the core is revolved; N is the total number of lines of force passing from the north pole through the core to the south pole. Each wire, therefore, on the periphery of the core cuts the total number of lines twice during every revolution; or, in other words, each outside wire cuts $2N$ lines of force per revolution. S is the number of outside wires on the periphery through which the current flows in *series*, and n is the number of complete revolutions per second of the core. Therefore, the maximum E. M. F. in volts that is obtained from the brushes is found by the formula

$$E = \frac{2NSn}{10^8}. \qquad \textbf{(1.)}$$

That is to say, *the E. M. F. obtained from a number of conductors connected in series and moved across a magnetic field is equal to twice the number of lines of force multiplied by the number of conductors in series and by the revolutions per second of the core, divided by* 100,000,000. For example, assume the total number of lines N passing from the north pole through the core to be 3,000,000, or $N = 3,000,000$. In the diagram, Fig. 28, there are 8 outside wires in series, or $S = 8$. If the core is rotated at 2,100 revolutions per minute, $n = \frac{2,100}{60} = 35$ revolutions per second. Substituting the values in the formula gives $E = \frac{2NSn}{10^8} = \frac{2 \times 3,000,000 \times 8 \times 35}{100,000,000} = 16.8$ volts, or the difference of potential between the brushes $+B$ and $-B$ on open circuit. The difference of potential between the brushes when the external circuit is closed is somewhat smaller than when

no current is flowing; because, as in the case of the voltaic cell, a part of the total E. M. F. developed is required to overcome the internal resistance of the coil itself.

The formula $E = \frac{2NSn}{10^8}$ holds equally true for the drum core, Fig. 30. In both cases, the number of outside wires through which the current flows in *series* is equal to one-half the total number of outside wires. Hence, by using the same magnetic field and rotating the cores at equal speeds, the E. M F generated in both cases will be equal.

24. The foregoing articles demonstrate the elementary principles and physical theory of a *dynamo*. A **dynamo,** therefore, is a machine for converting mechanical energy into electrical energy by electromagnetic induction. It has three essential features, viz.: (1) a magnetic field; (2) a conductor, or several conductors, called an **armature,** in which the electromotive force is generated by some movement relative to the lines of force in the magnetic field; and (3) a *commutator*, or a *collector*, from which the current is collected by two or more conducting brushes.

In all dynamos, the magnetic field is produced either by a permanent magnet or by an electromagnet, and they are classified accordingly; for present purposes, however, it is sufficient to consider only the uniform magnetic field lying between the poles of some large magnet. In the preceding article, the armature core and commutator were assumed to be fastened rigidly to a shaft and the shaft supported by suitable bearings in such a position that the core would rotate in the magnetic field with its axis of rotation at right angles to the lines of force. The shaft with core and commutator was assumed to be rotated by some exterior mechanical power. The armature conductors were wound directly upon the core and rotated with it. If it were not for mechanical considerations, however, only the armature conductors would need to be rotated; the core could remain stationary.

ARMATURE REACTIONS.

25. When the current is flowing through the armature conductors, it produces several effects upon the magnetic field; and the field, in return, reacts upon the current. These effects will be considered before describing the typical forms of dynamos.

Consider the case of a single conductor in which a current is flowing from a voltaic battery or a continuous-current dynamo, and a magnet. It has been shown that a magnet and a conductor conveying an electric current exert a mutual force upon each other; or, in other words, each tends to produce motion in the other. In the case of a compass placed over or under a conductor conveying a current, if the magnetic needle be held rigidly and the conductor be allowed to swing freely in a horizontal plane, it would tend to place itself at right angles to the length of the needle. In general, *when a conductor conveying an electric current is placed in a magnetic field, the conductor will tend to move in a definite direction and with a certain force, depending upon the strength and direction of the current, and upon the direction and density of the lines of force in that field.*

Imagine that a conductor conveying an electric current is placed across a uniform magnetic field, and that it lies in a position at right angles to the lines of force. For example, the diagram in Fig. 31 represents a cross-sectional view of a uniform magnetic field, the dots representing the ends of the lines of force and the heavy line a conductor conveying a current. The direction of the lines of force is assumed to be downwards, that is, piercing the paper; or, in other words, the observer is looking along

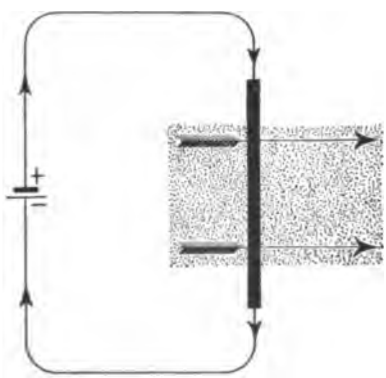


FIG. 31.

the lines of force towards the face of a south magnetic pole. The lines of force along the conductor from the top to the bottom of the magnetic field act upon the current in the conductor with equal intensities, and all tend to move the conductor in the same direction. This action, if the magnetic field is uniform, is similar to that of a uniformly distributed load upon a beam tending to move or bend it.

The motion imparted to the conductor is perpendicular to the lines of force, and also perpendicular to the flow of current in the conductor. To fulfil these conditions, therefore, the conductor in Fig. 31 must tend to move bodily either to the right or left across the field; in which of these two directions it moves depends upon the relative direction of the lines of force with the direction of the current in the conductor. In this case, if the direction of the lines is downwards, piercing the paper, and the current flows *from* the top *to* the bottom of the diagram, as indicated by the small arrow-heads, the conductor will tend to move from the left to the right in the direction in which the two large arrows are pointing. If the direction of the lines of force only is changed, the conductor will tend to move in the opposite direction, i. e., from the right to the left; or, if the direction of the current in the conductor only is reversed, the conductor will tend to move also from right to left across the field. But should both the direction of the lines of force and the direction of the current in the conductor be changed, the conductor would still tend to move from left to right.

26. There is a convenient thumb-and-finger rule for remembering the direction of motion imparted to a conductor conveying an electric current when placed in a magnetic field; it is similar to the rule for generated currents, Art **8**, with the exception that the *left hand* is used instead of the *right*.

Rule.—*Place thumb, forefinger, and middle finger of the left hand each at right angles to the other two; if the forefinger points in the direction of the lines of force, and the*

middle finger points in the direction towards which the current flows, then the thumb will point in the direction of movement imparted to the conductor.

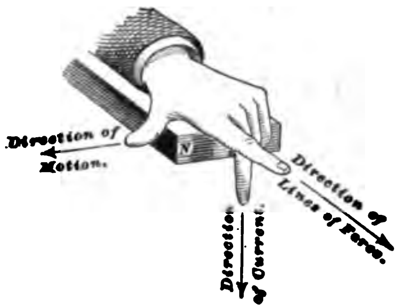


FIG. 32.

For example, in Fig. 32, if a vertical conductor in which a current is flowing downwards is placed in front of the north pole N of a magnet, it will tend to move in the direction as indicated by the thumb.

27. Comparing the rule in Art. **8** with that given above, it will be seen that the two appear to oppose each other; or, in other words, the current which flows in the former case, according to the latter rule, tends to oppose the motion of the conductor and move it in the opposite direction. This is exactly what takes place. When a conductor is moved across lines of force, an electromotive force is generated which tends to send a current in a definite direction; if the circuit is open and no current flows, it requires no force to move the conductor across the field; but if the circuit is closed and a current flows through the conductor, then the action of the lines of force on the current opposes the original motion and tends to stop or retard the conductor. The opposing force is proportional to the strength of current flowing in the conductor; that is, if a current of 10 amperes acts with a certain force, a current of 20 amperes will act with twice that force, and so forth. Hence, the stronger the current in the conductor, the greater will be the force necessary to keep the conductor moving in the original direction. The above explanation will be made clearer by the graphical illustration in Fig. 33. The diagram represents a cross-sectional view of a magnetic field, the direction of the lines of force being downwards, piercing the paper. If the conductor $c\ c'$ be moved across the field by some

exterior motive power in the direction indicated by the arrows *a*, *a*, a current will flow through the circuit in the direction indicated by the small arrow-heads, according to the rule given in Art. **8.** The length of the arrows *a*, *a* may also serve to represent the magnitude of the force that moves the conductor. As the current flows through the conductor, the lines of force immediately react upon it, producing a *counter*

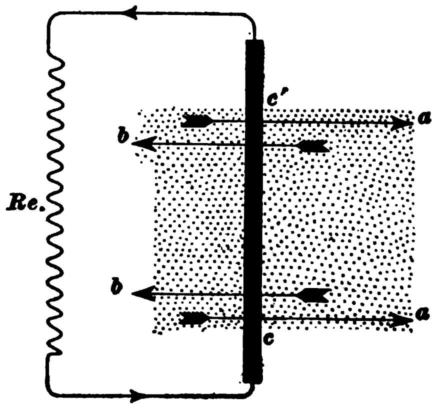


FIG. 33.

force which tends to stop the conductor and move it in the direction indicated by the arrows *b*, *b*. The counter force would never actually move the wire in the direction of the arrows *b*, *b*, but it exerts a dragging effect upon the conductor, which would reduce its speed and almost stop its motion if the exterior motive force were not increased. So long as the conductor is moved, the applied motive force is always larger than the counter force, as graphically represented by the relative lengths of the arrows.

28. The above principle explains the action of converting the mechanical energy into electrical energy in the dynamo. For example, suppose that an armature is rotated at a constant speed in a magnetic field by some exterior motive force, as, for instance, by a belt from an engine. If the armature is properly wound and connected to a commutator, an electromotive force is generated in the outside conductors on the core, causing a difference of potential between the brushes. If the brushes are not connected to an external circuit, and no current is flowing through the armature, it requires no energy to rotate the armature, excepting a small amount to overcome the friction of the

shaft in the bearings and the loss in the armature iron by eddy currents. By connecting the brushes to an external circuit, however, and allowing a current to flow through the armature, the conditions are altered. The lines of force react upon the current in the conductors, tending to rotate the core in an opposite direction and to retard its motion; the stronger the current, the greater will be the retarding effect. Hence, in order to keep the speed constant and to generate a constant E. M. F., more energy must be supplied to the pulley from the engine. This retarding effect of the current is known as the **counter torque** of a dynamo. The word torque, which will appear later in connection with the action of motors, means simply *turning* force.

It can be mathematically proven that the mechanical energy delivered to the armature from any exterior source is exactly equal to the electrical energy obtained from the armature plus the energy lost in mechanical friction, eddy currents in the iron, and other small losses, which will be described subsequently.

29. Besides producing a counter torque in the armature, the current tends to distort or crowd the lines of force from their original position in the magnetic field. This effect is termed **armature reaction,** and will be understood by investigating the magnetic effects of the current in the armature when the armature is removed from between the poles of the field-magnets. In the diagram, Fig. 34, the current is flowing through the armature coil in the same direction as represented in

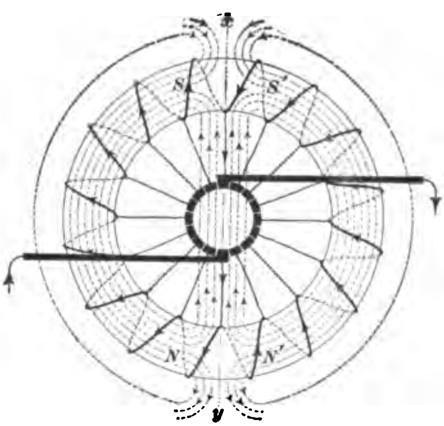


FIG. 34.

Fig. 28. The current circulating around the armature coil in two directions acts as a magnetizing force upon the core and produces two electromagnets. According to the rule for magnetic polarity, the two magnets thus formed oppose each other at the two neutral spaces of the armature; that is, their like poles N, N' and S, S' tend to act in opposite directions at the neutral spaces. As previously explained, lines of force can never intersect each other, and will always produce consequent poles when acting in opposite directions at one place. Therefore, in this case, two consequent poles are formed in the core, one at each neutral space, as shown in the diagram. The polarity of the consequent poles, of course, depends upon the direction in which the coil is wound upon the core and the direction in which the current is generated. The same action occurs when the armature is rotated between the poles of a magnet and a current flows through the coil, although the conditions are somewhat altered. The lines of force from the magnet tend to pass through the core nearly at right angles to those produced by the current. The lines can never intersect, however, and they crowd and distort one another in order to coincide in direction. The lines that pass out from the north pole of the magnet tend to enter the core at the south consequent pole and to pass out from the core at the north consequent pole. At the same time, the south consequent pole is shifted towards the north pole of the magnet, and the north consequent pole towards the south pole of the magnet. The diagram in Fig. 35 represents the manner in which the magnetic field is distorted by the reaction of the armature current. In the case where the armature was removed from the magnetic field, the consequent poles coincided with the neutral space; but when the armature is replaced, as in the diagram, the consequent poles are shifted backwards against the direction of rotation, and the neutral spaces are moved forwards in the opposite direction, as indicated by the imaginary diameter $x\,y$. As the positions of the neutral points on the commutator depend upon the positions of the neutral spaces on the core, they are also shifted

forwards in the direction of rotation when the current flows through the armature; hence, the brushes must be moved

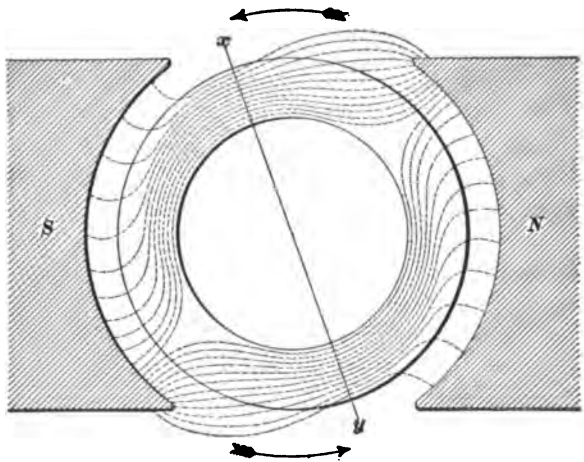


FIG. 35.

forward in order to obtain the full E. M. F. generated in the coil. The stronger the current, the farther forwards the brushes should be shifted.

30. From the fact that in all dynamos of this character the relation of the lines of force, direction of rotation, and direction of current are constant, *the neutral spaces are always shifted forwards in the direction of rotation when the current becomes stronger*, no matter how the coil is wound upon the armature, or in which direction the lines of force pass through the core.

These armature reactions are not confined entirely to the ring core, but are produced with the same effects in a drum-core armature, such as represented in Fig. 30. If the direction of the current is traced by the arrow-heads upon the conductors, it will be seen that the current is flowing upwards along the face of the core in front of the north pole, as represented by the open circles, Fig. 36, and downwards in front of the south pole, as represented by the solid circles. The lines of force surrounding each conductor in which the

current is flowing coincide with those around the adjacent conductors, forming a large number of long lines which pass through the core and produce consequent poles at the neutral spaces, as shown in Fig. 36. The direction of the lines of force around the conductors in which the current is flowing downwards corresponds with the movements of the hands of

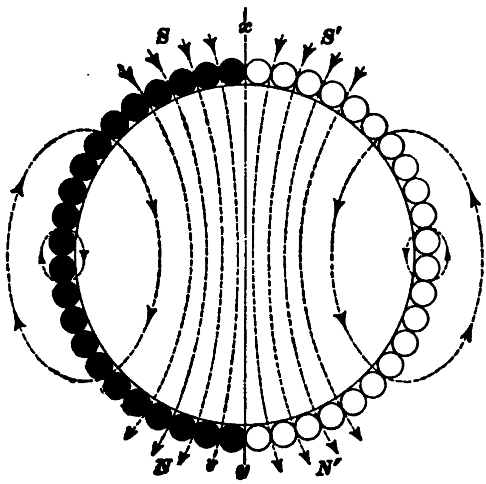


FIG. 36.

a watch, while the direction of the lines around the other conductors is opposite. The lines from all conductors, however, coincide in direction in passing through the center of the core. When the armature is rotated between the poles of a magnet, the field is distorted, and the neutral spaces shifted forwards in a manner similar to that described for the ring core.

31. Armature reactions not only distort the magnetic field, but also have a tendency to reduce the total number of lines of force from the magnet, and thereby diminish the E. M. F. generated in the armature. This effect, however, can be almost entirely eliminated by increasing the strength of the field, or, in other words, by increasing the number of lines of force passing through the core. This fact leads to the consideration of *field-magnets*.

FIELD-MAGNETS.

32. In Art. **24** it was stated that the magnetic field in all dynamos is produced from either a permanent magnet or an electromagnet. A dynamo of the first class is called a **magneto-machine.** Such machines are necessarily small on account of the difficulty of making large permanent magnets; in fact, the field in most magneto-machines is produced by several permanent magnets placed side by side. The magnets are usually of the U-shaped pattern, of hard steel, and with a recess bored out between the ends of the poles to admit the armature, as shown in the diagram, Fig. 37.

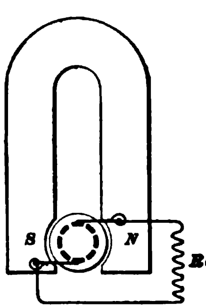


FIG. 37.

As the majority of magneto-machines are made for testing and signaling purposes where alternating currents can be used to advantage, the armature is wound with one large coil of wire, and the two ends of the coil are connected to two separate collector rings, as shown in Fig. 38. The alternating current is obtained from two brushes, one rubbing against

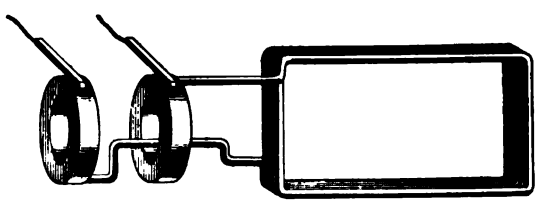


FIG. 38.

each collector ring. The brushes can bear upon the collector ring at any position relative to the coil and the field-magnets, since all parts of one collector ring are at the same potential in any instant. By comparing this coil with that in Fig. 13, it will be seen that the current obtained from the two brushes flows in two directions during every revolution.

33. In nearly all dynamos furnishing current for lamps, power, and other commercial purposes, the magnetic field is

produced by an electromagnet. This class of dynamos is divided into various types, depending upon the manner in which the current is obtained to excite the field-magnets.

34. The first class of machines to be considered is termed a **separately-excited** dynamo, from the fact that its field-magnets are excited or magnetized by a current from some external source, as, for instance, a voltaic battery, or another continuous-current dynamo. The connections of a separately-excited dynamo are represented in Fig. 39. The magnetizing coils are wound around the cores of a magnet and connected to the terminals of a voltaic battery *B*. The exciting current flows from the battery around the cores of the field-magnet in such a direction as to produce a closed magnetic circuit through the armature, and has no connection whatever with the current obtained from the brushes by rotating the armature. If the strength of the exciting current is not changed, the difference of potential between the brushes of the dynamo when the armature is rotated at a uniform speed remains constant so long as the external circuit is open; but when the external circuit is closed, the difference of potential gradually diminishes as the strength of current increases, owing to the internal resistance of the armature conductors and the reactions of the armature current on the field.

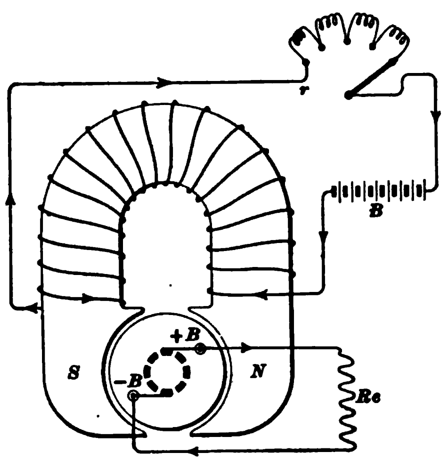


FIG. 39.

35. The **magnetizing force** is that which produces the lines of force in the magnet. Its strength is proportional

to the strength of current flowing and to the number of coils or complete turns around which the current circulates. The total number of turns multiplied by the strength of the current in amperes will give the magnetizing force in **ampere-turns.** It has been proven that 10 amperes circulating around 20 turns exert precisely the same magnetizing force as 1 ampere circulating around 200 turns, or as 200 amperes circulating around 1 turn. In each of these cases, the magnetizing force is 200 *ampere-turns.* But the number of lines of force produced in an electromagnet is not directly proportional to the magnetizing force in *ampere-turns.* The strength of the magnet in lines of force depends upon the permeability of the magnetic substances used in the core. The permeability varies greatly in different magnetic substances, depending upon both the physical condition and the chemical composition of the substance. In general, *wrought iron*, *soft sheet iron*, and *steel* have greater permeability than cast iron, and, whenever available, should be used in field-magnets in preference. The permeability, however, of all magnetic substances changes with every stage of magnetization. In all kinds of magnetic substances, the permeability decreases when the magnetism is increased beyond a certain limit. This tendency of the substance to become less permeable is called **magnetic saturation**; that is, the substance becomes *saturated* with lines of force and can not hold any more. A limit is never reached where actual saturation takes place, but there is a limit beyond which it becomes impracticable to magnetize the substance. The practical saturation in wrought iron, soft sheet iron, and cast steel is when there are between 120,000 and 130,000 lines of force per sq. in. of sectional area of the iron, measured on a plane at right angles to the lines of force in the magnet. In gray cast iron, the practical saturation limit is from 60,000 to 70,000 lines of force per sq. in. Hence, when these limits are exceeded, it requires an enormous increase in the *ampere-turns* to produce a slight change in the number of lines of force in the magnet. In general, however, the field-magnets of dynamos are

designed with the density of the lines of force below the saturation limits, and it is safe to assume that any change in the strength of the current circulating around the magnetizing coils produces a corresponding change in the number of lines of force passing through the magnetic circuit. Consequently, if the strength of the current in the field coils of a *separately-excited* dynamo is increased as the current in the armature becomes stronger, the E. M. F. obtained from the brushes will remain practically constant. This is usually accomplished by inserting an adjustable resistance-box, or field rheostat *r*, in series with the battery and field coils, and decreasing the resistance as the difference of potential between the brushes tends to drop.

36. The second class of machines with an electromagnet is termed a **self-exciting shunt dynamo,** or simply a **shunt dynamo,** from the fact that the exciting current for the field-magnet is furnished by the dynamo itself, the

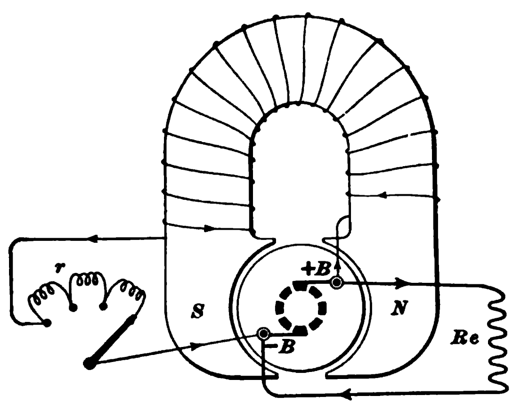


FIG. 40.

field coils being connected in *shunt* with the external circuit from the brushes. In Fig. 40, one terminal of the magnetizing coil is connected to the positive brush, and the other to a binding-post on the field rheostat *r*; the negative brush is connected to the arm of the field rheostat. If the resistance of the rheostat is neglected or cut out, it will be seen

that the total difference of potential exists between the terminals of the magnetizing coils when the dynamo is generating its maximum E. M. F. The magnetizing coils of a shunt dynamo, however, consist of a large number of turns of fine copper wire, thus making the resistance large in comparison with the difference of potential between the field terminals. In well-designed dynamos the resistance of the shunt coil is large enough to allow not more than about 5% of the total current of the dynamo to pass through the field coils; for, according to Ohm's law, the strength of current in amperes circulating around the field coils is equal to the difference of potential in volts between the brushes, divided by the resistance in ohms in the field coil, neglecting the resistance of the rheostat. For example, suppose that the difference of potential between the brushes of a shunt dynamo is 500 volts when a current of 10 amperes is flowing from the armature. If 5% of this current is required to excite the field-magnets, the strength of current circulating around the field coils is $10 \times .05 = .5$ ampere; and if E_e is the E. M. F. at the brushes, C_s is the current in the shunt field, and R_s is the resistance of the shunt field, then, according to Ohm's law, $R_s = \frac{E_e}{C_s} = \frac{500}{.5} = 1{,}000$ ohms.

37. When a shunt dynamo is rotated at a constant speed, an appreciable length of time elapses before the armature generates a maximum E. M. F. after the field circuit is closed, and in some cases a self-exciting dynamo will generate no E. M. F. until after it has been once separately excited. The starting of a dynamo to generate an E. M. F. is termed **picking-up,** or **building-up.** If the field current of a dynamo is open so that no current flows through the magnetizing coil, the armature would generate no E. M. F. when rotated, providing the field-magnets were not permanent magnets; consequently, when the field circuit is closed on a shunt dynamo, no current will flow through the magnetizing coils, because there is no difference of potential between their terminals. But nearly all

magnetic substances become permanent magnets in a slight degree after once being magnetized.

This permanent magnetism is called **residual magnetism,** since it *resides* in the metal after the magnetizing force has been removed. In general, soft iron and annealed steel retain only a small amount of magnetism, and in some cases the residual magnetism is imperceptible. Chilled iron and hardened steel retain residual magnetism in large quantities. Artificial or permanent magnets are made by placing a piece of hardened steel in a dense magnetic field or in contact with another magnet. Lodestone is the result of a natural residual magnetism. Iron and its alloys will also become slightly magnetized in the process of refining and working.

From these facts it will be seen that the cases where field-magnets do not exhibit some residual magnetism are exceedingly rare. The armature conductors when cutting the lines of force of the residual magnetism generate a small E. M. F., and this E. M. F., in turn, causes a feeble current to circulate around the magnetizing coils when the field circuit is closed. The residual magnetism is, therefore, reenforced by the magnetizing effect of the current, which is followed by an increase in the E. M. F. generated, and that, in turn, by a stronger current in the field. These actions and reactions continue until a limit is reached where the fields become saturated with magnetism, and the number of lines do not increase at such a rapid rate; finally, both the E. M. F. and the current in the field become constant.

38. The difference of potential between the brushes of shunt dynamos gradually decreases as the current from the armature becomes stronger, on account of the internal resistance of the armature conductors and the reactions of the current on the field. The effect is even more marked than in separately-excited dynamos, because a decrease in the difference of potential between the brushes causes a corresponding decrease on the field terminals, thereby weakening the current in the magnetizing coils. In order to

compensate for the decrease in the E. M. F., a field rheostat *r* of comparatively high resistance is connected in the field circuit, and so adjusted that when no current is flowing in the external circuit only enough current flows through the field to produce the normal difference of potential between the brushes; this normal difference of potential between the brushes is kept constant, as the load increases, by gradually cutting out, or short-circuiting, the resistance coils of the rheostat.

NOTE.—The word *load* as used above is a common expression for *current* in dynamos generating a constant potential, and the student should become familiar with its use.

39. The third class of machines whose field-magnets are excited by an electric current are termed **self-exciting series dynamos,** or simply **series dynamos.** The magnetizing coils of a series dynamo are connected directly in *series* with the external circuit; that is, all the current from the armature circulates around the magnetizing coils and flows through the external circuit. The connections of a *series* dynamo are shown in Fig. 41. The current starts from the positive brush $+B$, circulates around the external circuit *Re*, from thence through the magnetizing coils back to the negative brush $-B$. The action of a series dynamo differs widely from that of a shunt dynamo. In the first place, no E. M. F. is generated in the armature unless the external circuit is closed and a current flows from the brushes, that is, neglecting the small E. M. F. generated by the residual magnetism. In the second place, the difference of potential between the brushes depends upon the strength of current flowing from the armature. The E. M. F., however, is not directly proportional to the

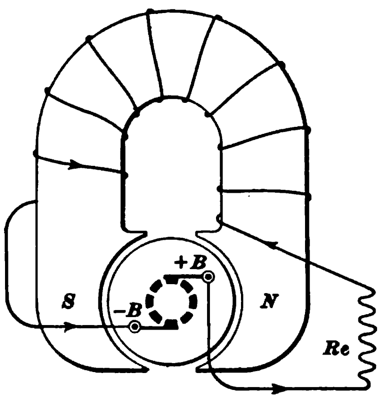


FIG. 41.

strength of the current unless the internal resistance and reactions of the armature are negligible. Compared with the coils on a shunt dynamo, the magnetizing coils of a series dynamo are made of a few turns of a large conductor. This is necessary, because the coils usually are required to carry the total current from the armature; the conductor is made large to carry the current without heating, and only a few turns are used to secure the proper degree of magnetization, since that is proportional to the *ampere-turns*.

40. The E. M. F. of a series dynamo may be regulated in three different ways, viz.: (1) By controlling the strength of current in the external circuit as previously described; (2) by *short-circuiting*, or *cutting out*, part of the magnetizing coils; and (3) by *shunting* part of the current around the magnetizing coils.

The second of the above methods of regulating the E. M. F. will be understood from the diagram in Fig. 42. *S F* represents the magnetizing coils. *A* is a contact arm which travels in either direction along the line *x y*, one end making contact with the ends *a*, *b*, *c*, *d*, etc. of the series field, and the other being always connected to the external circuit *Re*. As the arm is moved towards *x*, the turns between it and *k* are cut out of circuit; that is, the current from the armature circulates around only those coils between the arm and *a*; if the strength of the current remains constant, the magnetizing force is thereby reduced. On the contrary, when the arm is moved towards *y*, additional turns are connected in circuit, and the magnetizing force is increased.

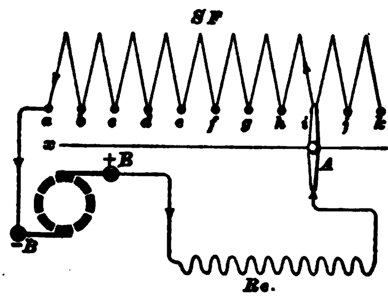


FIG. 42.

41. The third method of regulating the E. M. F. of a series dynamo changes the strength of the magnetizing current instead of varying the number of turns in the coil.

This effect is accomplished by connecting a resistance R, Fig. 43, in parallel or shunt with the series field coils $S F$, the current dividing between the two circuits inversely proportional to their separate resistances. Consequently, to

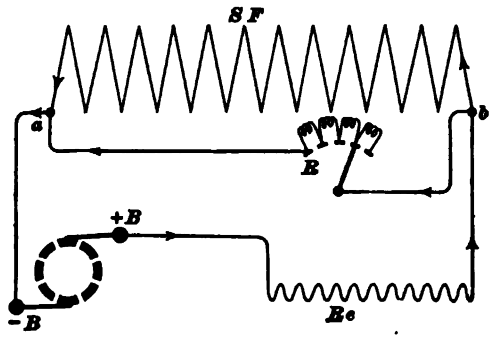


FIG. 43.

increase the magnetizing force on the field-magnets, the resistance R of the shunt circuit is increased, and *vice versa*. The total current from the armature is made to pass through the magnetizing coils by opening the shunt circuit entirely.

42. In the dynamo previously described, the regulation of the E. M. F. is not automatic; it is accomplished by a mechanical movement of an arm or contact. This movement is sometimes imparted by a magnet controlled by the current from the armature, but more often the E. M. F. is automatically regulated in the dynamo itself by a combination of the *shunt* and *series* magnetizing coils. Such machines are termed **compound,** or **shunt-and-series,** dynamos. In

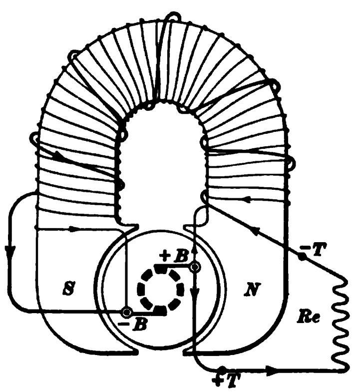
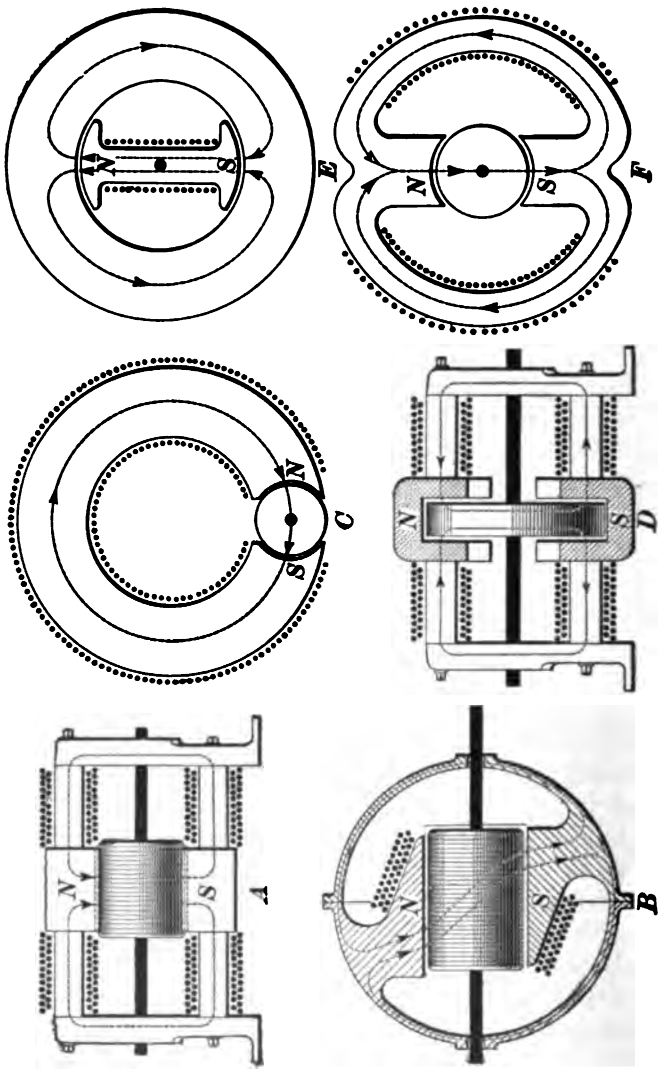


FIG. 44.

Fig. 44, the shunt coils consist of a large number of turns of fine insulated wire wound upon the core of the magnet.

The series coils, consisting of a few turns of large insulated wire, are wound over the shunt coils. The main part of the current from the armature flows from the positive brush $+B$, through the external circuit *Re*, thence through the series coils to the negative brush $-B$. The two terminals of the shunt coils are connected to the two brushes $+B$ and $-B$, respectively. But the series and shunt coils are so wound that the currents in both circulate around the core of the magnet in the same direction when connected, as shown in the diagram. The action of both currents, therefore, is to produce the same polarity in the magnet, the shunt current being reenforced by the series current. When the dynamo is not loaded, that is, when no current is flowing in the external circuit, and the armature is rotated at normal speed, the normal E. M. F. is generated in the armature due to the magnetic field produced by the shunt coils alone. Upon closing the external circuit, however, the difference of potential between the brushes *tends* to decrease, and would continue to decrease, as previously described in a simple shunt machine, if the series coils were neglected. The current circulating through these, however, reenforces the magnetizing force of the shunt coils, and immediately increases the number of lines of force in the field, which, in turn, raise the difference of potential between the brushes to normal. These actions are produced simultaneously, and, to all appearances, the difference of potential between the brushes remains normal for all changes of load in the external circuit. This method of regulating the E. M. F. of a dynamo is called **compounding.** The **terminals** of a dynamo are the binding-posts to which the external circuit is connected; in a series, or compound, dynamo one terminal is attached to the outside end of the series coils, as $-T$ in Fig. 44, and the other terminal is connected directly to the brush, as represented by $+T$ in the figure. It is desirable in a great many cases to **over-compound** a dynamo, or, in other words, to wind a sufficient number of turns on the series coils so as to increase the difference of potential between the terminals

of a dynamo above normal when the load increases. The expression **per cent. over-compound** means that the difference of potential between the terminals increases a given



per cent. of the normal when the load is at a maximum. For example, supposing the normal voltage of a dynamo is

500 volts, and it is 10% over-compound at full load; the difference of potential between the terminals of the machine at full load is, therefore, $500 + (500 \times .10) = 550$ volts.

In some cases it is an advantage to connect the shunt

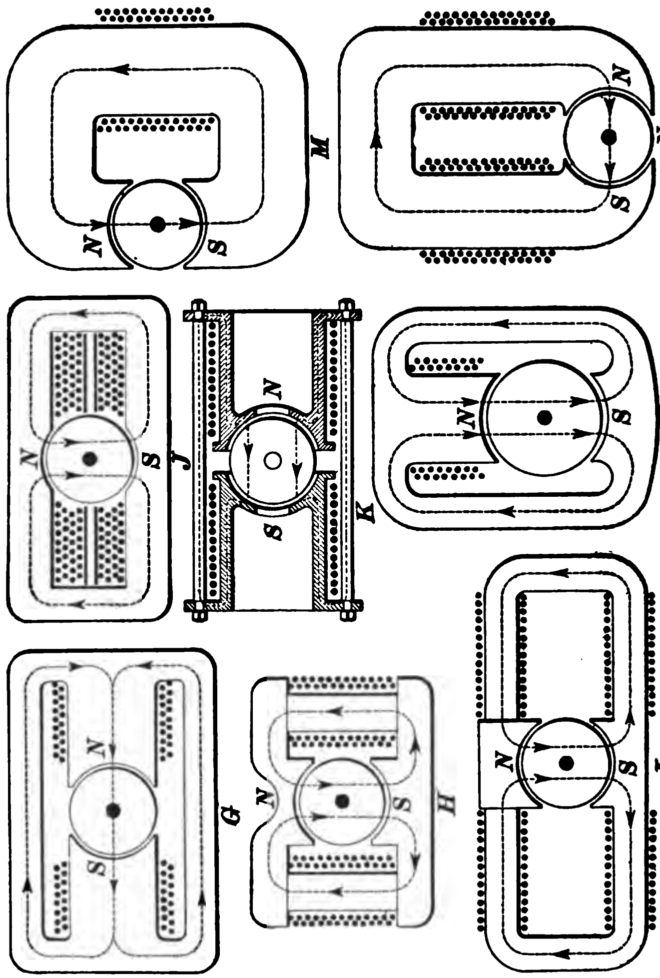


Fig. 45.

field outside the series coils; that is, in Fig. 44, to connect the negative end of the shunt coil to the negative terminal $-T$, instead of being connected to the negative brush $-B$. This connection is seldom used in practice.

TYPES OF BIPOLAR FIELD-MAGNETS.

43. The various types of field-magnets for dynamos in which the armature revolves between only one pair of poles are shown in Fig. 45. It is customary to speak of such machines as **bipolar dynamos,** from the fact that only one pair of poles is presented to the armature. The broken lines and arrow-heads in each of the separate cuts represent the paths of the lines of force which must pass lengthwise through the coils from the north pole to the south pole. The black dots indicate a cross-section through the wires which form the coils.

Field poles are distinguished as follows with respect to the coils producing them: (*a*) **Salient poles;** (*b*) **Consequent poles.**

In all cases where a single coil is used, or where, if two coils are used, they are wound so as to produce unlike poles at their free ends, the poles are called salient poles. When two coils are used and wound so as to make their adjacent poles similar, the resultant poles are called consequent poles.

Referring to Fig. 45, salient poles exist in fields *B*, *C*, *G*, *J*, *K*, *L*, *M*, *N*, and consequent poles in *A*, *D*, *E*, *F*, *H*, *I*. The adjacent coils in *A*, Fig. 45, have their adjacent poles at *N* and *S* similar. Were these poles opposite, the magnetic flux would circulate around the magnets without passing through the armature.

TYPES OF DYNAMOS.

44. Dynamos are divided into three general types, depending on the character of their currents. These three types are:

1. **Constant-potential dynamos,** in which the E.M.F. remains constant and the strength of current (continuous) changes with the load or external resistance.

2. **Constant-current dynamos,** in which the strength of current (continuous and pulsating) remains constant and the E. M. F. changes with the load.

3. **Alternating-current dynamos,** the current from which alternates or reverses direction with great rapidity and whose E. M. F. is constant. In ordinary alternating-current dynamos the reversals average generally either 7,200 or 16,000 per minute.

NOTE.—A dynamo which generates current for power purposes has been conventionally termed a *generator*, to distinguish it from a machine for lighting.

CONSTANT-POTENTIAL DYNAMOS AND GENERATORS.

45. The foregoing articles have demonstrated the principle and regulation of constant-potential dynamos, but only one form has been considered, namely, a dynamo in which a ring or drum armature is rotated between only one pair of poles from a U-shaped magnet. Theoretically, however, constant-potential dynamos can be built with one armature revolving between any number of pairs of poles, although in practice eight pairs of poles are seldom exceeded. Machines having more than one pair are called **multipolar dynamos.**

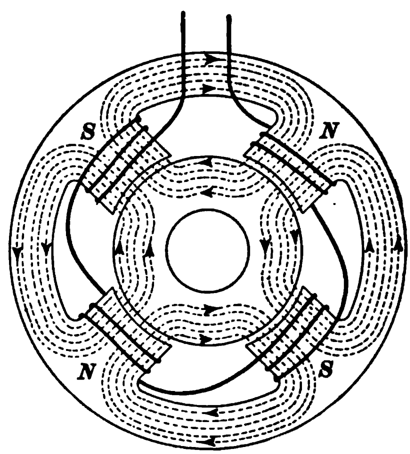


FIG. 46.

In multipolar dynamos the pole-pieces and field cores are fastened into one magnetic yoke, more or less circular in shape, as shown in Fig. 46, which represents the magnetic circuits of a four-pole dynamo. A magnetizing coil is wound upon each field core, and the four coils are connected in series in

such a manner that when a current circulates around the coil, it produces first a north pole and then a south pole. The lines of force from each field core divide into two magnetic circuits in the yoke and armature, as represented in the diagram. Their density is practically uniform, however, where they pass from the north pole into the armature core, or from the armature core into the south pole. In nearly all multipolar dynamos this same principle of polarity is applied, that is, every *other* pole is of like polarity, and lines of force from each core divide into two magnetic circuits, in the armature and in the field yoke.

46. The process of generating an E. M. F. is similar to that in bipolar machines, but there are some points which

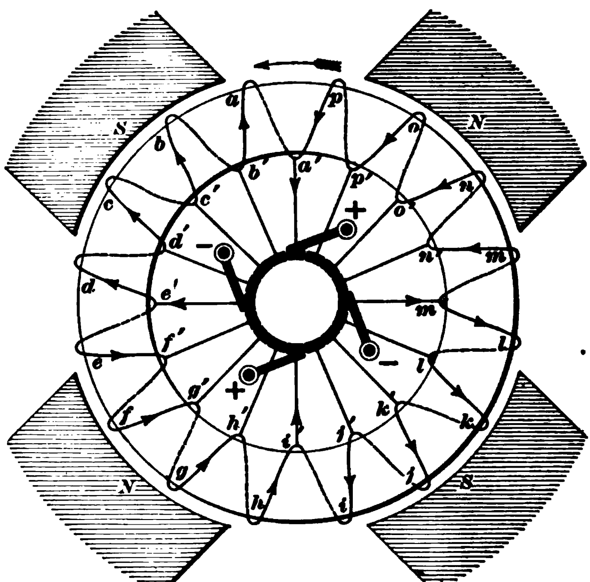


FIG. 47.

should be understood. Consider first the case of a ring core with a closed-coil winding as shown in the diagram, Fig. 47. If the armature is rotated in the direction of the large arrow, the E. M. F. generated in the conductors in front of the south poles will tend to act downwards along the face of the pole, while that generated in front of the north pole will

tend to act upwards. By tracing out, by aid of the small arrow-heads on the conductors, the direction in which the E. M. F. acts, it will be seen that there are four points where the E. M. F. acts in opposite directions. The action of the electromotive forces is to meet at a' and i' and to divide at e' and m'. The segments connected to a' and i' have the same potential and form two *positive* neutral points of the commutator; the segments connected to e' and m' have the same potential and form two neutral points of the commutator. Hence, four brushes are necessary—two positive and two negative. The current is obtained from the armature by connecting the two positive brushes in parallel to one terminal of the external circuit, and the two negative brushes to the other terminal, as shown in Fig. 48. The currents from the positive brushes unite to form the current in the external circuit and divide again between the negative brushes. The current in the armature is divided into four circuits in parallel instead of two, as in bipolar dynamos, and the maximum E. M. F. that is obtainable from the brushes is equal to that generated by the active conductors in one of the circuits only. For example, the difference of potential between the positive and negative brushes in Fig. 47, when no current is flowing, is equal to the E. M. F. generated in one-quarter of the outside wires on the core; or, in other words, the total E. M. F. of the armature is proportional to the number of outside wires connected in series.

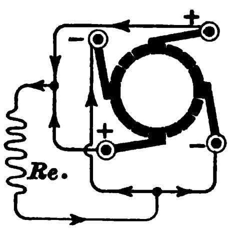


FIG. 48.

The current in a ring armature wound and connected in this manner, if placed in a field-magnet of six poles, would divide into six circuits in parallel; if the armature is placed in a field-magnet of eight poles, the current would divide into eight circuits in parallel, and so on. An armature winding of this character is called a **parallel,** or **multiple, winding,** since the current divides into as many circuits in parallel as there are poles in the field-magnet.

47. It is possible, however, to connect and group the conductors in an armature for a multipolar dynamo so that

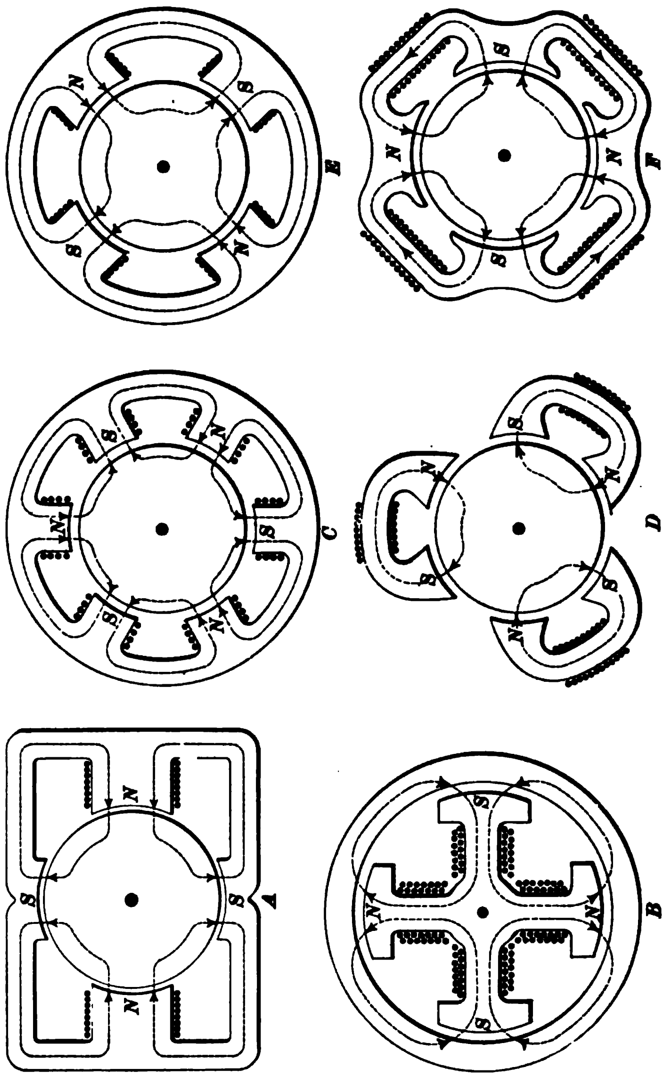


FIG. 49.

the current divides into two circuits only, making the number of active conductors in series equal to one-half the total

number of outside wires on the core. This armature winding is termed a *series winding*, since one-half of the total outside wires is the largest possible number that can be connected in series and produce a continuous current.

There are many different methods of connecting and winding armatures for generating a continuous current, the method used depending upon the character of the current and E. M. F. desired. Drum windings as well as ring windings are connected in a variety of ways for multipolar and bipolar dynamos, but the principle of commutation and generation of E. M. F. does not differ from that previously described; the E. M. F. is always proportional to the number of outside or active wires connected in series.

48. The regulation of multipolar dynamos for constant potential is accomplished by the changing of the strength of the magnetizing force, as in the bipolar machines. In a compound dynamo the series coils are wound on each field core and all connected together in parallel or series, whichever is more expedient.

49. Types of Multipolar Field-Magnets.—The various types of multipolar field-magnets are shown in Fig. 49. Consequent and salient poles are used as in bipolar field-magnets, but the type generally employed has salient poles alone, as in *C* and *E*. *A* embodies both consequent and salient poles. In *B* the field-magnet is surrounded by the armature and is known as an *internal-pole* dynamo. The field of this dynamo revolves, and the armature is kept stationary. The armature in all cases is that part of a dynamo in which the current is generated. Each type of field-magnet in the above figure has its own special advantages, but all represent good design.

50. Mechanical Construction.—Heretofore, only the principles of a dynamo have been considered; its mechanical construction in detail depends upon the requirements of the machine and upon the originality and taste of the designer. A few general remarks, however, on the construction of the principal parts of the machine are necessary

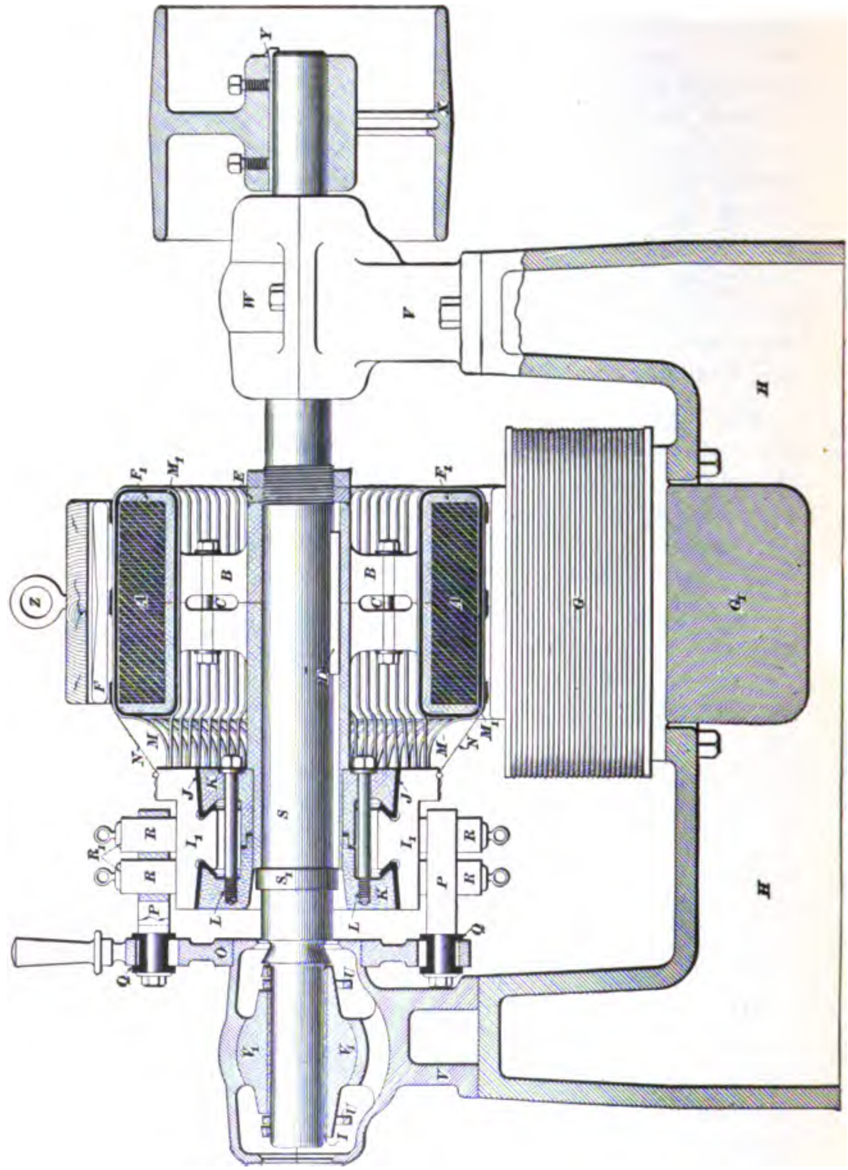


FIG. 50.

to give the student a clear conception of a complete dynamo ready for operating.

The mechanical construction of a typical bipolar dynamo is shown in Fig. 50, which is a vertical section taken along the center of the armature shaft. The parts of the machine shown in the figure are lettered, and the names of the parts corresponding to the letters are as follows:

A = Armature core, which may be either punchings from sheet iron or built up of fine annealed iron wire.
B = Armature spider for connecting core to shaft.
C = Armature spider bolts.
D = Armature key for fastening spider to shaft.
E = Armature lock-nut.
F = Pole-piece.
G_1 = Magnetic yoke.
G = Magnetizing or field coil.
H = Frame.
I_1 = Commutator bars or segments.
J = Commutator insulation.
K = Commutator shell or body, and rings for holding commutator segments in place.
L = Bolt for clamping commutator frame.
M = Armature leads, connecting armature winding to commutator.
N = Armature dressing or covering.
O = Rocker-arm or brush-holder yoke.
P = Brush holder.
Q = Insulating bushings.
R = Carbon brushes.
R_1 = Carbon-brush hammers.
S = Shaft.

$$\left.\begin{array}{l} T = \text{Bearing or brass.} \\ U = \text{Oil-rings.} \\ V = \text{Standard.} \\ W = \text{Cap for standard.} \end{array}\right\} \begin{array}{c} \text{Complete outfit} \\ \text{called} \\ \text{pillow-block.} \end{array}$$

X = Pulley.
Y = Key for pulley.
Z = Eye-bolt.

51. Frame.—The frame is made up of two castings; the upper one forms the magnetic yoke G_1 and pole-pieces F, and is bolted to the lower one H, which forms the base and is extended on either side to support the standards V, V. The pole-pieces are bored out to admit the armature core when wound; the standards are bolted to the base casting, and are so adjusted as to allow the armature core to revolve centrally between the pole-pieces. The magnetizing or field coils G, only one of which is shown in this cut, are wound on separate bobbins or spools, and one is slipped over each pole-piece.

52. Armature.—As generally used, the word **armature** includes the wound core and commutator mounted on the shaft ready for operating. In Fig. 50, the armature spider B is made in two halves; each half is provided with flanges F_1 at the ends to hold the disks or sheets of iron A in place. The disks are punched in circular rings from thin sheet iron annealed, and a large number are slipped over each half of the spider, which is then bolted together by long spider bolts C as shown. The spider usually has three or four arms joining the flanges to the hub, the armature conductors on the inside of the ring, in case of ring winding, being wound between the arms. The hub of the spider is bored out to slip over a portion of the shaft S; it rests against a turned shoulder S_1, and is held in this position by the armature nut E. The spider and core are made to revolve with the shaft by the aid of a key or feather D, fitted into the spider hub and into the shaft. The core and spider are insulated by mica, cloth, paper, etc., M_1, and the armature conductors are wound on them in the manner previously described, with armature leads properly connected to the winding at suitable places. After the core has been wound and the leads connected to the commutator, the winding is sometimes covered or dressed with cloth of suitable texture to prevent flying particles and dust injuring or short-circuiting the coils. The armature leads should be made of a flexible conductor or cable, insulated from one another with

cotton or rubber tape; an electrical contact of two leads will short-circuit and burn out the intervening coil. It is sometimes the practice to use the armature conductors themselves for leads by looping the conductor and connecting the end of the loop to the commutator. This is bad practice, however, and, except for small dynamos, ought not to be followed. A large solid copper wire is liable to become crystallized by the repeated vibration of the machine, and will eventually give way.

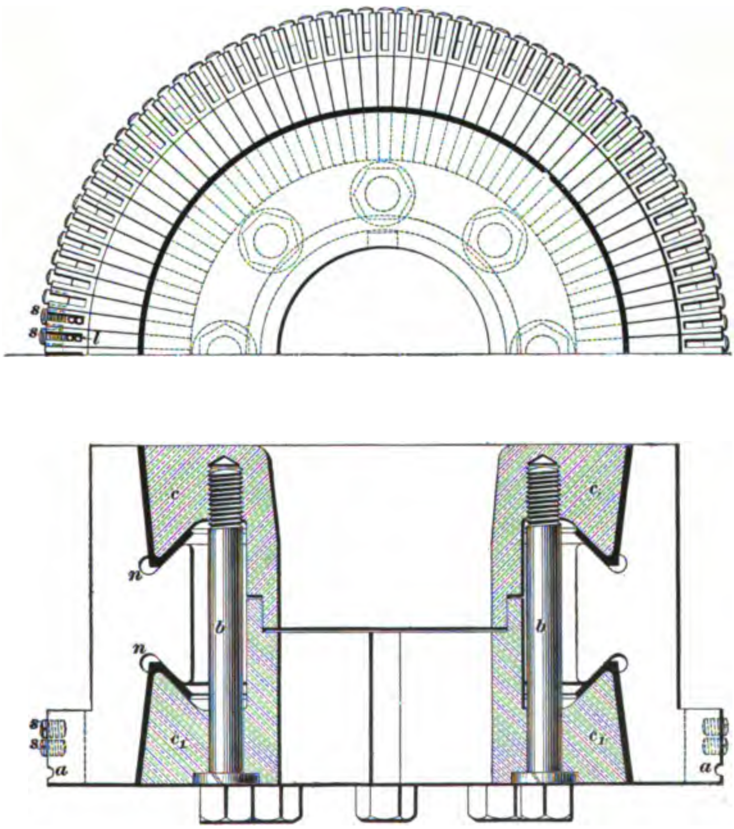


FIG. 51.

53. Commutator.—Every maker of dynamos has a special design of commutator, but all embody the same

general construction. Fig. 51 shows two enlarged views of a commutator such as is shown in place in Fig. 50. It will be noticed that the segments are broader on the outside of the commutator than near the center, thus providing for an equal thickness of insulation between all parts of adjacent bars. A portion *a* of each segment projects above the general level of the commutator surface, and is provided with a slot into which the armature leads are securely fastened by screws *s*, *s*, as shown at *l*. Sometimes the leads are soldered to the segments. The method of clamping and securely holding the segments is shown in the lower view. The commutator shell, it will be seen, consists of two rings $c\,c$ and $c_1\,c_1$, clamped together by bolts *b*, *b*. The notches *n* in the segments fit over corresponding projections on the rings, and as the bolts are tightened the segments are drawn firmly against the insulation which separates them. The commutator shell is usually made of brass, sometimes of cast iron. This shell is, of course, thoroughly insulated from the commutator segments. A key is fitted into the commutator shell and shaft to cause the commutator to turn with the shaft. The armature leads from the winding are soldered or screwed to ears or clips extending from each commutator bar, as shown by the cross-sectional view.

54. Brushes and Brush Holders.—In the cut of the machine in Fig. 50, the brushes shown are made of carbon and rub against the segments of the commutator radially, the pressure being regulated by a spring which is attached to a hammer pressing on top of the carbons. The carbons slide in slots in the brush holders, fitting snugly, with but little play or lost motion sideways. Both brush holders are provided with studs which pass through holes in the rocker arm, each stud being insulated from the arm by insulating bushings, as shown in the cross-sectional view. The rocker arm is fitted over the journal-box, and can be rocked or rotated to change the position of the brushes on the commutator as the position of the neutral points changes when the load is varied. This action is usually accomplished by a

handle attached to the rocker arm; and a thumb or set screw is provided to hold the rocker arm in position when properly adjusted. The current is taken from the brushes by a cable or flexible conductor connected to the brush holder, generally by the use of a small cable clip surrounding the stud. On a large class of dynamos it is customary to use copper brushes; that is, brushes made either of copper leaves, strips, wires, or gauze. Such brushes are built in a great variety of ways, and on constant-potential machines are generally used where the E. M. F. does not exceed 125 volts.

55. Journals or Bearings.—The armatures of most dynamos are generally driven at a high speed compared with the average rotating machinery, and hence it is important that the journals or bearings should be of the best design possible. In the dynamo shown in Fig. 50 the bearings are called **self-aligning** boxes; that is, the linings are allowed to find their own alignment with the shaft. This is accomplished by turning a spherical surface V_1 around the center of the lining, and turning the cap and standard to match, as shown in the cross-sectional view. The linings I in such a bearing are usually made of some composition metal, as bronze or gun-metal, for small machines; on large machines the linings are made of cast iron covered on the inside with babbitt metal.

The best practice in lubricating high-speed journals in dynamos is to make the bearings *self-oiling* or *self-lubricating;* that is, to design the bearings with a reservoir of oil below the journal, using some device to carry the oil from the reservoirs to the top of the journal, from whence it flows around the journals and drops back into the reservoirs again. This method produces a constant circulation of oil around the journals and allows the oil to be used over and over again.

A good method of automatically oiling or lubricating bearings on journals is shown in the cross-sectional view in Fig. 50. Two slots are cut across the top of each lining,

permitting two circular *oil-rings U* to rest upon the journals of the shaft; the diameters of the rings are made large in comparison with the diameter of the shaft, and their lower parts dip into the reservoirs of oil. When the shaft is rotated, the friction between it and the inside of the oil-rings causes the latter to revolve, thus carrying the oil which adheres to the bottom part of the rings to the top of the journal, where it finds its way between the linings and the shaft.

In general, any freely lubricated journals can be used in dynamos or generators.

56. Driving Mechanism.—The armatures of nearly all dynamos are driven in one of the following ways: (1) By using a flat belt passing over a pulley on the armature shaft. (2) By using several ropes, side by side, running in a grooved pulley. (3) By connecting the armature directly to the crank-shaft or shaft of the driving machine, which, in most cases, consists of a steam-engine, steam turbine, or water-wheel. In any of the above methods, the driving mechanism should be amply capable of transmitting the total output of the dynamo with a suitable factor of safety.

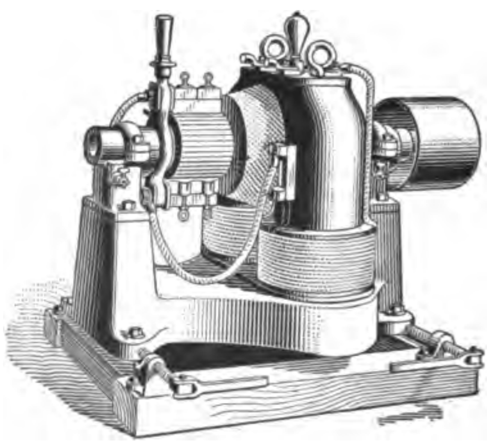


FIG. 52.

57. A perspective view of the bipolar dynamo just described is shown in Fig. 52. In the cut the machine is

represented as ready for operating, and is mounted upon sliding rails which are attached to the wooden *bed-plate*. Two adjusting screws, one on each side of the machine, are used to move the dynamo along the rails, thereby loosening or tightening the belt as the circumstances may require. The current passes from the brush holders through flexible copper cables to two terminals fastened to, but insulated from, the pole-pieces; from the terminals the current passes through the series winding on the field or magnetizing coils, and thence to a small connection board on the top of the pole-pieces. An incandescent lamp is connected between the main terminals of the connection board, and is used to indicate when the machine is generating its normal E. M. F. A lamp used for this purpose is usually called a **pilot lamp.**

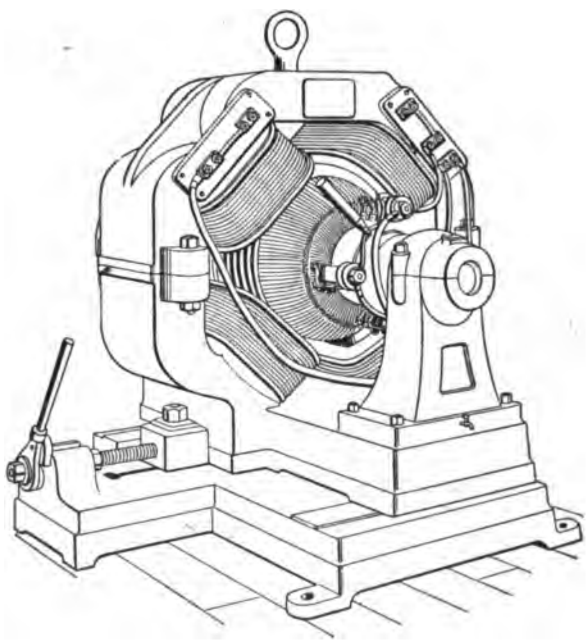


FIG. 53.

58. A multipolar dynamo for developing a constant potential and ready for operating is shown in Fig. 53. In this machine the frame is made of two main castings; one

consisting of the upper magnetic yoke and two pole-pieces, and the other consisting of the lower magnetic yoke and two pole-pieces, from which project two extensions for supporting the pillow-blocks. The dynamo slides upon a cast-iron bed-plate, and adjustment is made by a screw, as in the case of the bipolar dynamo.

The two dynamos previously described are illustrations taken from actual practice, and embody some special features which are not found in other machines of the same character; they were selected, however, on account of their simplicity, to convey to the student a general idea of how electrical principles are combined with mechanical construction.

EFFICIENCY OF CONSTANT-POTENTIAL DYNAMOS.

59. As previously stated, a dynamo is a machine for converting or transforming mechanical into electrical energy. In any transformation of energy, the total amount of energy is constant; when energy which is manifested in one form disappears, the same quantity will always appear again in another form or in several other different forms. This action is exactly that which takes place in a dynamo. A certain amount of mechanical energy is delivered to the armature shaft of the dynamo by a belt or some other transmitting device; a large portion of the energy is converted into electrical energy in the armature conductors, and is transmitted to the external circuit, while the rest of the energy, usually the smaller portion, is converted directly or indirectly into heat energy in the different parts of the dynamo itself. The amount of energy delivered to the armature shaft is always equal to the energy appearing in the external circuit from the brushes, plus the energy converted into heat in the dynamo itself.

In a dynamo the mechanical energy delivered to the armature shaft is usually called the **input**; the electrical energy appearing in the external circuit from the brushes is called the **output**, and the energy converted into heat directly or

indirectly in the dynamo itself is termed **energy losses**, or simply **losses**. This last term is not a strictly true one; for the energy converted into heat in the dynamo is lost only in relation to its utility—it can not be utilized to an advantage, and if too intense, endangers the life of the machine.

From what has been stated, it will be seen that the *input* of a dynamo is always equal to the *output* at the brushes, plus the *losses* in the machine itself; or, in other words, the losses in the dynamo are equal to the difference between the *input* and the *output*. It is assumed in the above statement that the *input*, *output*, and *losses* are reduced to the same units. For example, suppose that 20 horsepower is delivered to the armature shaft of a dynamo where the *output* from the brushes to the external circuit is 13,428 watts. Reducing the 20 horsepower to watts gives $20 \times 746 = 14{,}920$ watts; hence, the losses in the dynamo are equal to the difference between the input of 14,920 watts and the output of 13,428 watts, or $14{,}920 - 13{,}428 = 1{,}492$ watts.

60. It is more convenient, however, to express the relation of the *input*, *output*, and *losses* of a dynamo in percentage; that is, the output as well as the losses may be expressed as a certain per cent. of the input. The relation of the input to the output of a dynamo, expressed in percentage, is termed the **efficiency** of the machine.

Let $I =$ the input of a dynamo;
$O =$ the output;
$\mathsf{E} =$ the per cent. efficiency.

Then, the per cent. efficiency of a dynamo may be found by the formula

$$\mathsf{E} = \frac{100 \times O}{I}. \qquad (2.)$$

That is, *to find the per cent. efficiency of a dynamo, divide the output in watts by the input in watts and multiply by 100.*

For instance, in the above example, the efficiency, by formula **2**,

$$\mathsf{E} = \frac{100 \times 13{,}428}{14{,}920} = 90 \text{ per cent.}$$

61. The relation of the input to the heat losses in a dynamo, expressed in percentage, is termed the **per cent. loss.**

Let $L =$ per cent. loss.

Then, the per cent. loss in a dynamo may be found by the formula

$$L = \frac{100\ (I - O)}{I}. \qquad (3.)$$

That is, *to find the total per cent. loss in a dynamo, divide the difference between the input and the output in watts by the input in watts and multiply by 100.*

EXAMPLE.—(*a*) What is the per cent. efficiency of a dynamo if 10 horsepower is delivered to the armature shaft and the output from the brushes is equivalent to 6,341 watts? (*b*) What is the total per cent. loss in the dynamo when running under these conditions?

SOLUTION.—Reducing the input of 10 H. P. gives $10 \times 746 = 7,460$ watts input. (*a*) By formula **2,** the efficiency

$$E = \frac{100 \times 6,341}{7,460} = 85 \text{ per cent. Ans.}$$

(*b*) By formula **3,** the total loss

$$L = \frac{100\ (7,460 - 6,341)}{7,460} = 15 \text{ per cent. Ans.}$$

The efficiency of a dynamo depends upon its character, construction, condition when tested, its capacity (or output), losses, and various other conditions; in fact, two dynamos of the same construction and capacity seldom show exactly the same efficiency. The following list, however, will give the student a general idea of the approximate per cent. efficiencies which should be obtained from constant-potential machines of different capacities, or outputs, under ordinary conditions met with in practice:

From 750 to 1,500 watts output inclusive, about 75% efficiency.

From 3,000 to 5,000 watts output inclusive, about 80% efficiency.

From 7,500 to 10,000 watts output inclusive, about 85% efficiency.

From 15,000 to 100,000 watts output inclusive, about 90% efficiency.

From 150,000 watts output and upwards, from 91 to 93% efficiency.

The method of actually testing a dynamo to find its efficiency and losses is beyond the scope of this paper; the above, however, will serve as a guide to the student when computing the necessary power required to drive dynamos of different capacities or outputs.

62. When the output of a dynamo and its corresponding efficiency are given, the input necessary may be found by the formula

$$I = \frac{100 \times O}{\mathsf{E}}. \qquad \textbf{(4.)}$$

That is, *the input necessary to drive a dynamo, when its output nd efficiency at that output are given, is obtained by dividing the output by the per cent. efficiency and multiplying the quotient by 100.*

EXAMPLE.—The efficiency of a constant-potential dynamo is found to be 85% when giving an output of 6,341 watts; find the input in horsepower necessary to drive its armature shaft under these conditions.

SOLUTION.—By formula **4**, the input necessary $I = \frac{100 \times 6,341}{85} =$ 7,460 watts. The equivalent of 7,460 watts in horsepower is $\frac{7,460}{746} =$ 10 horsepower, which is the power required to drive the armature shaft of the dynamo under the stated conditions. Ans.

63. When the input of a dynamo and its corresponding efficiency are given, the output may be found by the formula

$$O = \frac{I\mathsf{E}}{100}. \qquad \textbf{(5.)}$$

That is, *the output of a dynamo, of which the input and the efficiency at that input are given, is obtained by multiplying the input by the per cent. efficiency and dividing by 100.*

EXAMPLE.—An input of 35 horsepower is delivered to the shaft of a dynamo; if its efficiency at that input is 89.5%, find its output in watts.

SOLUTION.—The equivalent of 35 horsepower is $35 \times 746 = 26{,}110$ watts. By formula **5**, the output of the dynamo under these conditions, $O = \frac{26{,}110 \times 89.5}{100} = 23{,}368.45$ watts. Ans.

64. The total loss of power in a dynamo can be separated into smaller losses, depending upon the manner in which the loss is produced and the part of the dynamo in which it occurs. In ordinary cases, all the losses will come under one of the following heads:

1. Mechanical-friction loss.
2. Core loss.
3. Field loss.
4. Armature loss.

Friction Losses.—The larger part of the loss due to mechanical friction takes place between the bearings and journals. The brushes rubbing on the commutator produce some friction and consequent loss, but the amount is small, and in most cases need not be considered. The per cent. of power lost in mechanical friction necessarily depends upon the construction and condition of the bearings and journals, upon the size of the machine, and, to some extent, on the method of driving the armature shaft. Under ordinary conditions, the loss in mechanical friction should not exceed 5% of the input of dynamos from 1,500 up to about 10,000 watts output, and 3% of the input of dynamos from 15,000 to 100,000 watts output. For example, suppose that a dynamo has an efficiency of 88% at its rated output of 22,000 watts, and a test shows that 2.5% of the input is lost in mechanical friction. The total loss in the machine is $100 - 88 = 12\%$, of which 2.5% is lost in friction; the remaining 9.5% loss is due to other causes. The total input to the machine, from formula **4**, is $\frac{22000}{88} \times 100 = 25{,}000$ watts; hence, the power lost in friction is $\frac{25{,}000 \times 2.5}{100} = 625$ watts.

65. Core Losses.—The **core loss** is the energy converted into heat in the iron disks of the armature core when they are rotated in the magnetic field. A small portion of this loss is due to eddy currents generated in the revolving core disks, as explained in Art. **16**; the larger portion of the loss is due to a *magnetic friction* which occurs whenever the direction of the lines of force is rapidly changed in a magnetic substance. When the magnetism of an electromagnet is rapidly reversed—that is, when the direction of the lines of force is suddenly changed several times in rapid succession by reversing the direction of the magnetizing current—the iron or steel in the core becomes heated, which necessitates a certain amount of energy being expended. This effect is due to a kind of internal *magnetic friction* by reason of which the rapid changes of magnetism cause the iron to grow hot. This effect is called **hysteresis.**

The energy expended by hysteresis is furnished by the force which causes the change in the magnetism, and in the case of an electromagnet where the magnetism is reversed by the magnetizing current being reversed, the energy is supplied by the magnetizing current.

The same effect is produced when the iron of the armature core is rapidly rotated in the constant-magnetic field of the dynamo; this case differs from the electromagnet only in the fact that the magnetic lines of force remain at rest and the iron core is made to rotate. Since the core is rotated from the armature shaft, the energy lost in hysteresis is furnished by the force which drives the shaft.

The loss of energy due to hysteresis depends (1) upon the hardness and quality of the magnetic substance in which the magnetic change takes place, (2) upon the amount of metal in which the reversal takes place, (3) upon the number of complete reversals of magnetism per second, and (4) upon the maximum density of the lines of force in the metal. Building the core of iron disks does not affect the hysteretic loss; it only reduces the eddy currents. Hysteretic loss is greatly reduced by using soft annealed iron, which exhibits only slight traces of residual magnetism;

for where the residual magnetism is large, the loss due to hysteresis is large in proportion. The hysteretic loss increases in a certain ratio with the magnetic density and the number of reversals per second; hence, these quantities are kept within reasonable limits. In well-designed dynamos the magnetic density in the armature rarely exceeds 85,000 lines of force per sq. in., and the maximum number of complete reversals of magnetism in the armature core is about 133 per second. In bipolar dynamos the number of complete reversals of magnetism in the armature is equal to the number of revolutions per second at which the armature shaft is driven; in multipolar machines the number of reversals is equal to the number of revolutions of the armature shaft, multiplied by the number of *pairs of poles*. For example, if the armature of a four-pole dynamo is driven at 600 revolutions per minute, or 10 revolutions per second, the number of complete reversals of magnetism in the armature core is $10 \times 2 = 20$ per second.

In a well-designed dynamo, the core loss, including eddy currents and hysteresis, should not exceed 2% of its input when delivering its rated output from the brushes.

66. Field Losses.—In self-exciting dynamos, a portion of the electrical energy generated in the armature is required to excite the field-magnets. This energy is considered as one of the losses of the dynamo, since it does not appear in the external circuit and it is entirely dissipated in the form of heat.

In a series-connected dynamo, where the total current from the armature passes through the magnetizing coils, the power in watts is equal to the square of the current, multiplied by the resistance of the series turns, as already demonstrated in formula **20,** Part 1. If, then, C is the total current from the armature, r is the total resistance of the series coils, and W is the watts lost in the series coils, then, $W = C^2 r$. For example, suppose that a series dynamo generates 200 volts between its terminals when a current of 100 amperes is flowing from its brushes through its series

coils and through the external circuit. The total output of the dynamo is, then, $100 \times 200 = 20,000$ watts. If the total resistance of the series coils is .1 ohm, then the number of watts (W) required to excite the field-magnets $= C^2 r = 100^2 \times .1 = 100 \times 100 \times .1 = 1,000$ watts.

67. In a shunt dynamo which generates a nearly constant potential for limited strengths of current in the armature, the field coils, as stated in Art. **36,** usually consist of a large number of turns of fine wire, offering a high resistance compared with the field coils of a series dynamo. The inside and outside ends of the shunt field coils are connected to the positive and negative brushes, respectively, of the dynamo in parallel with the external circuit, thereby allowing the full potential of the dynamo to act against the resistance of the coils. Then, from Ohm's law, the current in the shunt coil is equal to the electromotive force of the brushes, divided by the resistance of the coils. Let E_e represent the difference of potential between the brushes of the dynamo when running at normal speed and fully excited, let r_s represent the resistance of the shunt coils, and C_s represent the current in the shunt coils. Then, from Ohm's law, the current in the shunt coils is given by the formula $C_s = \frac{E_e}{r_s}$. For example, suppose that a shunt dynamo, when running at a constant speed, generates a constant difference of potential of 110 volts, and the resistance of the magnetizing coils from the positive connection to the negative connection is 55 ohms; or $E_e = 110$ volts and $r_s = 55$ ohms. Then, the current in the shunt coils would be given by substituting these values in the above formula, or $C_s = \frac{E_e}{r_s} = \frac{110}{55} = 2$ amperes.

This gives the strength of current in the shunt coils, but does not indicate the amount of power required to constantly excite the field-magnets. By formula **19,** Part 1, the power in watts, $W = C E$; that is, it is equal to the current in amperes flowing through the shunt coils, multiplied by the difference of potential in volts between the terminals

of the shunt coils. We have found in this case that the current $C = 2$ amperes and the E. M. F. $E = 110$ volts; then, $W = 2 \times 110 = 220$ watts, which represents the power required to excite the field-magnets.

Since the power in watts can be expressed in terms of resistance and electromotive force, or resistance and strength of current, the number of watts dissipated in the shunt coil is also given by either formula **20** or **21**, Part 1.

All other conditions being similar, the same number of watts will be dissipated in a shunt field coil as in a series coil, provided an equal amount of magnetizing force is produced in the two cases.

68. In a compound-wound dynamo, the field loss consists of two losses, one in the series coil and the other in the shunt coil. The loss in the series coil depends upon the strength of current flowing from the dynamo, as in the case of a simple-series dynamo, while the loss in the shunt coil is constant, irrespective of the load on the machine; provided, of course, the dynamo generates a constant electromotive force for all loads. This can readily be understood from the following example: A dynamo is compounded to generate 220 volts between its terminals for all loads up to its rated capacity; that is, when the current from the armature becomes stronger and the difference of potential between the terminals tends to fall, the current in passing through the series coil strengthens the field-magnets sufficiently to keep a difference of exactly 220 volts between the terminals of the dynamo. Assume the resistance of the shunt coil to be 275 ohms and that of the series coil to be .055 ohm. At a rated output of 4,400 watts, the current flowing through the series coil and into the external circuit is $\frac{4400}{220} = 20$ amperes (assuming the connections are made for a *short shunt*). At all loads the current in the shunt coil is $C_s = \frac{E_e}{r_s} = \frac{220}{275} =$ .8 ampere, and the loss of power in the shunt coil is $W_s = E_e \times C_s = 220 \times .8 = 176$ watts; even when the external circuit is open the loss in the shunt coil remains constant, or

176 watts in this particular case. The loss in the series coil, however, varies directly with the square of the current passing through it. In this example, the loss in the series coil is $W = C^2 \times r = 20^2 \times .055 = 22$ watts; at half load, or 10 amperes, the loss is $W = 10^2 \times .055 = 5.5$ watts, etc.; at no load there is no current in the series coil, and, consequently, no loss. The total field loss in a compound dynamo is the sum of the losses in the series and shunt coils. For instance, in this example, the total field loss at full load is 198 watts; at half load, 181.5 watts, and at no load, 176 watts.

69. The amount of power lost or dissipated in the field coils of a dynamo depends (1) upon the capacity of the dynamo, (2) upon its design, and (3) upon the amount of copper used in the coils. In the last condition it is obvious that in order to produce a certain number of *ampere-turns*, the current in amperes required could be made exceedingly small by using a large number of turns of copper wire, thereby reducing the electrical loss. A limit is reached, however, where it is not economical from a commercial standpoint to increase the amount of copper in order to save in electrical loss.

The per cent. loss in the field coils of dynamos varies from about 10% of the input to dynamos having an output of about 1,000 watts to as low as 1.5% to 2% of the input to dynamos having an output of 100,000 watts and upwards. For example, suppose that the input to a dynamo from an engine was 100 horsepower and the loss in the field coils was 2.5%. Under these conditions, how many watts are lost or dissipated in the field coils? Changing the input from horsepower to watts gives $100 \times 746 = 74,600$ watts, since one horsepower is equivalent to 746 watts. Hence, the number of watts lost in the field coils is $74,600 \times .025 = 1,865$ watts.

70. Armature Losses.—The principal armature loss is that produced by the current in flowing against the internal resistance of the armature, that is, the resistance

of the armature *conductors.* The *core losses* previously described could also be classed as part of the armature losses, but it is usual to consider them apart. The armature loss proper is usually termed the **copper,** or **wire, loss,** since it is due to the resistance of the armature conductors, which are composed of copper wire or bars. The internal resistance of an armature is an exceedingly variable quantity, depending upon the form, construction, size, number of conductors, size of conductors, etc. In constant-potential dynamos, generally speaking, the internal resistance of the armature must necessarily be comparatively small, since it determines the maximum strength of current that can be obtained from the dynamo, as will be seen subsequently.

The armature loss depends upon the amount of internal resistance and upon the strength of current flowing through the armature conductors. In a given armature the internal resistance remains constant at equal temperatures, while the strength of current varies with the load upon the dynamo at that particular moment; in other words, this loss only occurs when there is a current flowing through the armature—the stronger the current, the greater is the loss, and *vice versa.* As previously shown (formula **20,** Part 1), in all cases where an electric current flows against the resistance of a conductor, the loss of power in watts is equal to the resistance of the conductor in ohms, multiplied by the square of the current in amperes; hence, in an armature the number of watts lost in the armature conductors is equal to the square of the current in amperes flowing through the armature, multiplied by the internal resistance in ohms of the armature from the positive to the negative brush. If C represents the total current in amperes flowing through the armature and r_i the internal resistance in ohms from the positive to the negative brush, then $W_i = C^2 r_i$, where W_i is the number of watts lost in the armature conductors. From this fact, this armature loss is also designated as the $C^2 r$ *loss.* For example, suppose that the internal resistance of an armature from brush to brush is .125 ohm, and a total current of 40 amperes is flowing through the

armature. Determine the number of watts lost in the armature. Using formula **20,** Part 1, let $C = 40$ amperes and $r_t = .125$ ohm; then, $W_t = C^2 r_t = 40^2 \times .125 = 200$ watts.

The per cent. loss in armatures of constant-potential dynamos varies from about 12% of the input to dynamos having a rated capacity of about 1,000 watts to as low as 1.5% to 2% of the input to dynamos having a rated capacity of about 100,000 watts and upwards. For example, suppose that a dynamo was working under a load which required 50 horsepower to run it, and, at this rating, the armature loss alone amounted to 3% of the input; determine the number of watts dissipated or lost in the armature conductors. Changing the input from horsepower to watts gives $50 \times 746 = 37,300$ watts, since 746 watts are equal to one horsepower. The armature $C^2 r$ loss is, therefore, 3% of the input, or $37,300 \times .03 = 1,119$ watts.

71. Other Losses.—Aside from the four principal losses mentioned, other small losses occur in some machines when the armature is revolving. If large conductors are used in the winding of the armatures, a difference of potential is sometimes generated between the edges of the conductor in such a manner as to give rise to small eddy or local currents in the conductors themselves, and which do not appear in the external circuit and are useless. In some cases these local currents dissipate considerable energy and heat the armature badly when the machine is not loaded; but in a well-designed dynamo they are too small to be considered.

In an armature in which the conductors are wound in slots cut in the core disks, the teeth between the slots have a tendency to disturb the position of the lines of force where they enter and leave the polar faces. This movement causes local or eddy currents to be generated in the pole-pieces, thereby dissipating a certain amount of energy. These eddy currents in the pole-pieces are sometimes termed **Foucault currents,** in memory of the man who first recognized their existence. But, as in the previous case, a

well-designed dynamo will show but few traces of Foucault currents. Other local currents may occur in various parts of some dynamos on account of bad design, but it is only necessary here to treat specifically upon such losses as are common to all dynamos and impossible to eliminate.

72. From the four previous articles, the following summary will be a help to establish the rules of efficiency and losses:

Input = the power driving the dynamo, which is derived from some outside agency.

Output = input minus the total losses.

Total losses = the sum of the friction, core, field, armature, and other losses.

Per cent. efficiency $= \dfrac{\text{input minus total losses}}{\text{input}} \times 100$ or $\dfrac{\text{output}}{\text{input}} \times 100$.

Per cent. loss in friction $= \dfrac{\text{friction losses}}{\text{input}} \times 100.$

Per cent. loss in core $= \dfrac{\text{core losses}}{\text{input}} \times 100.$

Per cent. loss in field $= \dfrac{\text{field losses}}{\text{input}} \times 100.$

Per cent. loss in armature $= \dfrac{\text{armature losses}}{\text{input}} \times 100.$

THE OUTPUT OF CONSTANT-POTENTIAL DYNAMOS.

73. If a dynamo is so constructed as to give a constant potential at any load, it is evident that the current flowing is inversely proportional to the resistance of the external circuit; that is, if the external resistance is reduced, the amount of current will be correspondingly increased. There is a limit, however, to the amount of current that any given machine can give out, depending on one (or both) of two factors; namely, the **heating** and the **sparking**.

The heat that is being continually generated in the armature and field coils of a dynamo when working under load, due both to the $C^2 r$ *loss* and the *core loss*, is given off from the surface of the armature and of the whole machine to the surrounding air. This giving off of heat can only occur when the dynamo is hotter than the air, for if two bodies are equally hot, one can not give any heat to the other. Conversely, the greater the difference in temperature between two bodies, such as a dynamo armature and the surrounding air, the more heat will be given from the hot body to the cool.

74. When a dynamo is first started, it is at about the same temperature as the air, so that when the conductors in the armature begin to generate heat, this heat can not pass off to the air, but instead it raises the temperature of the armature, until it is enough hotter than the surrounding air to cause all the heat which is being generated to be given off.

If the amount of heat generated is practically constant, as will be the case if the load remains constant, the temperature of the armature will also remain constant, because the heat is given off as fast as generated; and if the load is increased so as to increase the amount of heat generated, the temperature will again rise until the armature is enough hotter than the air to give off all of this increased amount of heat.

It is evident, then, that when other conditions remain the same, the greater the load on a dynamo armature, that is, the more current it gives, the hotter it will get.

Now, at a certain temperature, the materials used in insulating the conductors of the armature, such as cotton, silk, shellac, paper, etc., will become *carbonized*, that is, charred, or otherwise rendered useless as insulating material. For a short time these materials will withstand a temperature considerably above the boiling-point of water (212° F.), but it has been found that if they are *continually* subjected to a temperature greater than about 180° F., they will gradually become carbonized; hence, as armatures

are expected to last several years, they should never be subjected to a continual temperature greater than about 170° F. Consequently, the amount of current which will cause a dynamo armature to heat to about 170° F. is the limiting amount which that armature can *safely* give.

75. As an armature must be a certain number of degrees hotter than the air in order to give off the heat generated, it is evident that if the air itself were originally of a high temperature, the armature would actually have a higher *temperature* when giving off a certain amount of heat than if the air were cooler; that is, for a certain amount of heat generated, the temperature of the armature will rise to a certain number of degrees *above the temperature of the air.* The average temperature of the air in places where dynamos are installed is often as high as 90° F., so the allowable rise in temperature of the armature above that of the air is about $170 - 90 = 80°$ F., and dynamos are usually rated according to this rise in temperature.

As *still* air is a very poor conductor of heat, most of the heat given off to it is carried away by the motion of the air; this motion is partly due to the air-currents set up by the rise of the heated air and the flowing in of the cooler air to take its place, but mainly to the air-currents set up by the motion of the armature itself. This latter effect is usually greater in ring than drum armatures, due to the more open construction of the former and to the *fan* action of the spider arms.

The heat generated in the field coils is disposed of in the same way as that of the armature; that is, it is given off to the surrounding air. The rise in temperature of the field coils is subject to the same limitations as the rise of the armature; i. e., it is usually limited to about 80° F above the temperature of the air.

76. By the *sparking* of a dynamo is meant the sparks which appear at the brushes, due to the *reversal of the current in the armature coils.* If the commutator is out of true, or has one segment higher or lower than the others,

or from other similar causes, there will be flashes or sparks at the brushes; but these are merely *mechanical* faults which can be easily remedied, and this is not what is meant by *sparking*. Referring to Fig. 28, it will be seen that in the armature coil $a' p p'$, when in the position shown, the general direction of the current is from right to left; but as soon as it moves into the position occupied by coil $b' a a'$, the general direction of the current is from left to right. Between these two positions the direction of the current must have been reversed, and this occurs during the time that the brush $+ B$ is resting on *both* the commutator segments which are connected to this coil ($a' p p'$).

Now, it has been shown (Art. **5**) that if the amount of current in a coil is suddenly increased or decreased, the *self-induction* of the coil tends to set up an E. M. F. in the coil which *opposes* the change in the strength of the current. Hence, when the current is reversed in the armature coil as it passes from one side of the brush to the other, the self-induction of the coil tends to prevent this reversal, so that when one of the commutator bars to which the coil is connected passes out from under the brush, the current flowing from the side of the armature into which the coil is entering (the left side in Fig. 28) in trying to pass through this coil is opposed by the E. M. F. of self-induction of the coil. Instead of passing through the coil, then, the current jumps from the commutator bar through the air to the end of the brush, making a spark. The same action takes place at each point of commutation.

In order to prevent this sparking, which burns the commutator bars and the brushes, the brushes are shifted forwards ahead of the actual neutral point, until at the same instant that the current in a coil is reversed the coil is moving in the edge of the magnetic field that spreads out from the pole-pieces, which generates in the coil an E. M. F. that is *opposite in direction to the E. M. F. of self-induction.* The consequence of this is that the E. M. F. of self-induction is diminished, which decreases the sparking. If the brushes are shifted to just the right position, the E. M. F. generated

in the coil by the magnetic field will just equal the E. M. F. of self-induction, and there will be no opposition to the reversal of the current; hence, no sparking. This is seldom actually done, as the E. M. F. of self-induction changes with every change in the strength of the current; but the effect of a certain amount of shifting of the brushes will usually so nearly counterbalance the E. M. F. of self-induction that the sparking will be slight at different loads.

77. It has been shown (Art. **29**) that the current in the armature winding reacts upon the magnetic field, forcing the actual neutral point ahead (in the direction of rotation). Now, if the brushes are moved ahead of this neutral point to avoid sparking, the effect is to move the consequent poles (due to the current circulating in the armature winding) also ahead, which shifts the neutral point still farther ahead, which requires a further slight shifting of the brushes. As long as the field due to the magnetizing coils is much stronger than the reactive effect of the armature, this action is slight, so that only a slight shifting of the brushes is necessary for practically sparkless operation. As the current in the armature increases, its reactive effect grows stronger, and a movement of the brushes is followed by a considerable movement of the neutral plane. Indeed, if the current in the armature is strong enough, the brushes may be shifted more than half way around the commutator without coming to the sparkless position. There is, therefore, a limit to the amount of current which can be taken from an armature (aside from its heating limit), which is reached when any amount of shifting of the brushes will not afford sparkless commutation.

This amount of shifting is generally confined to the space between the tips of the pole-pieces; that is, the brushes may be shifted until the coil short-circuited by a brush is at or just under the tip of a pole-piece.

In dynamos of good design the heating limit and sparking limit are reached with about the same current; that is. a current which will raise the temperature of the armature

above that of the air by the amount decided upon as a limit will also necessitate the brushes being shifted to the maximum allowable extent.

78. It is evident that while a brush is resting on two commutator bars at the same time, the coil connected between these two bars is *short-circuited*, the current from the two sides of the armature passing into the brush, one half through each of the two commutator bars, without passing through the short-circuited coil. The resistance which the current meets in passing from the bars into the brush is evidently the *contact resistance* of the surfaces which are in contact. When the brush rests equally on both commutator bars, the contact resistance opposed to each half of the current is the same; but as one of the bars moves out from under the brush and the other moves farther under it, the contact resistance is altered, and there is more opposition to the passage of one half the current into the brush than there is to the other. Now, with *metallic* brushes, which have a very low contact resistance if properly made, this difference is not enough to give any appreciable opposition to the current until the commutator bar is actually leaving the brush; hence, the current is *suddenly* forced to pass through the coil which has just been short-circuited. With *carbon* brushes the contact resistance is much greater than with metallic brushes; when the two bars are equally under the brush, this contact resistance is opposed equally to the current from each half of the armature, but as the one commutator bar begins to move from this position, the resistance opposing the current which is passing from that bar into the brush is great enough to force a part of the current around through the short-circuited coil and into the brush through the *other* commutator bar, in spite of the E. M. F. of self-induction of the coil.

From this it follows that with metallic brushes much more care must be taken to place the short-circuited coil in a field which will generate an E. M. F. equal to the E. M. F. of self-induction, since the absence of sparking depends

mainly on this point than with carbon brushes, since with these the absence of sparking depends both on generating an E. M. F. in the coil and on the contact resistance of the brush. On account of the increased resistance of contact, carbon brushes require less shifting for variations in load than do metallic brushes, and are generally used on machines where the variations in load are so frequent and extensive that a great deal of time would be spent in shifting the brushes, if this had to be done for every change in the load.

79. If the brushes are shifted so far forwards that the E. M. F. generated in the short-circuited coil is *greater* than the E. M. F. of self-induction, not only will the latter be neutralized, but a current will be sent around the coil through the commutator bars and the brush which short-circuits the coil. If this current is greater than the current which one half of the armature is supplying to the external circuit, it is evident that when the short-circuited coil moves over and becomes a part of that half of the armature, its current will be *reduced;* this reduction is opposed by the self-induction of the coil, as before, and sparking results. Since the circuit of the short-circuited coil is partly through the brush and its contact with the commutator bars, it is evident that with metallic brushes of low resistance the liability of the current in this coil becoming excessive is greater than with carbon brushes of (comparatively) high resistance. For the reason, therefore, that they are of higher resistance, carbon brushes will spark less than metallic brushes under the same conditions.

The cause and remedy for flashing and sparking at the brushes, due to mechanical imperfections or accident, will be taken up later.

DYNAMOS AND MOTORS.

(PART 3.)

CONSTANT-CURRENT DYNAMOS.

1. If an ordinary series-wound dynamo is connected to an external circuit whose resistance is variable, both the current and the E. M. F. will vary. For example, if the external resistance is increased, the current will be diminished; as the machine is series wound, this weakens the field, which lowers the E. M. F., and still further decreases the current. If the external resistance is decreased, the current and E. M. F. will each be increased.

In order to obtain a constant current in a circuit of variable resistance, it is necessary, then, to vary the E. M. F. of the machine as the resistance changes, and in the same proportion. There are many different devices for accomplishing this, as will be described.

In general, the field-magnets of constant-current dynamos may be bipolar or multipolar, with salient or consequent poles, according to the ideas of the designer. They are usually series wound. The armature windings, however, may be divided into two classes, **closed coil** and **open coil.**

CLOSED-COIL ARMATURES.

2. These have already been described in connection with constant-potential dynamos. Ring armatures are generally used in constant-current dynamos, on account of their good ventilation (see Art. **75,** Part 2), and from the ease with which any damaged coil may be repaired since a

coil can be replaced without disturbing others, which is not the case in the usual form of drum windings, where the coils overlap.

3. The methods used to regulate the E. M. F. of closed-coil armatures are as follows: (1) Varying the speed; (2) varying the strength of the field; and (3) shifting the brushes.

The first method is seldom used, though in special cases it is very convenient. The principle of this method is that with a simple series-wound dynamo, if the external resistance is increased, decreasing the current and E. M. F. (Art. **1**), the speed may be increased until the E. M. F. rises to a point where it will force the normal current through the external circuit; if this adjustment of the speed is made as rapidly as the external resistance changes, the current will be maintained at a constant value.

4. The second method has been described in Arts. **40** and **41**, Part 2, in connection with series-wound dynamos. It is evident that this same principle may be applied to constant-current machines, so as to properly vary the E. M. F. The range of this method of regulation is quite limited, because the strength of the field can not be economically forced beyond the point where the iron begins to be saturated (Art. **35**, Part 2), and if it is much reduced, the armature reaction (which is constant, since the current is constant) will cause the neutral point to considerably alter its position.

5. The third method is almost universally used in this type of machines. It has been pointed out (Art. **19**, Part 2) that the greatest difference of potential in a (bipolar) closed-coil armature exists between the two opposite coils which are in the neutral spaces; so, to get this maximum difference of potential between the brushes, they are placed on the opposite commutator segments which are connected to these two coils. Now, if the brushes are shifted from this position, although the E. M. F. generated in the armature is not altered, the *difference of potential between the brushes*

is reduced; for, although the circuit through the armature winding is still divided into two parts connected in parallel between the brushes, the separate E. M. F.'s of all the coils in each of the two parts are not all in the same direction. This may be more plainly seen by examining Fig. 28, Part 2.

6. If there were no armature reaction, shifting the brushes to a point half way around the commutator from the neutral space would reduce the difference of potential between them to zero, and in positions between these two, the difference of potential would be proportional to the amount of shift. Since the coils short-circuited by the brushes would be moving in strong magnetic fields, there would also be violent sparking. (See Art. **79,** Part 2.)

There is, however, a very considerable armature reaction in dynamos of this type, which is so proportioned with respect to the strength of the field that it has two effects. One is to shift the neutral point so that the difference of potential between the brushes is not quite proportional to the amount of shift; but this is of little importance compared to the second effect, which is that the tendency of the current in the armature winding to form consequent poles at the points where the current enters or leaves the winding through the leads to the commutator (Fig. 34, Part 2) actually *forces the lines of force of the field away from the armature at these points*, leaving only a weak field to influence the short-circuited coil. By proper proportioning of the armature winding, this results in little or no sparking at the brushes, especially as the amount of current in a constant-current machine seldom exceeds 10 amperes, which allows of the use of such a narrow brush that the time during which a coil is short-circuited is so short that the current in the coil does not have time to become large enough to cause serious sparking.

The brushes may be shifted by hand to get the desired regulation, but as this would require constant attention, it is usual to shift the brushes automatically, by devices on or

near the dynamos. These devices are usually controlled about as follows: Electromagnets are connected in the main circuit, and are so adjusted that when any change in the external resistance causes the current to increase or decrease from normal, the corresponding movement of the magnet keeper mechanically connects the rocker-arm of the dynamo to some sort of driving mechanism, so that the brushes are properly shifted. When they reach such a point that the current is again at its normal value, the electromagnet (usually called the *controlling magnet*) disconnects the rocker-arm from the driving mechanism, and the motion of the brushes ceases until some change in the external circuit calls for a new adjustment.

The mechanical parts of the various brush-shifting devices are quite different in the different makes of constant-current machines. In the following description of the principal features of some of the best known types of closed-coil, constant-current machines, the types of regulating devices used will be taken up more in detail.

PRINCIPAL CLOSED-COIL CONSTANT-CURRENT DYNAMOS.

7. Wood Dynamos.—These machines have bipolar, consequent-pole, series-wound field-magnets of the type illustrated at *A*, Fig. 45, Part 2, and ring-wound armatures of quite large diameter.

The regulator on all except the largest size of this dynamo is such as is shown in Fig. 1 (*a*) and (*b*). To reduce the sparking to a minimum, it has been found desirable to use two positive brushes a, a_1, located a little distance apart on the commutator, and two negative brushes b, b_1, located opposite the positive brushes. The brushes are mounted on opposite ends of the rocker-arms r and r_1, so that simply shifting these two effects the shifting of the four brushes. The angle between the rocker-arms r and r_1 of each pair of brushes is variable, preserving a distance between the

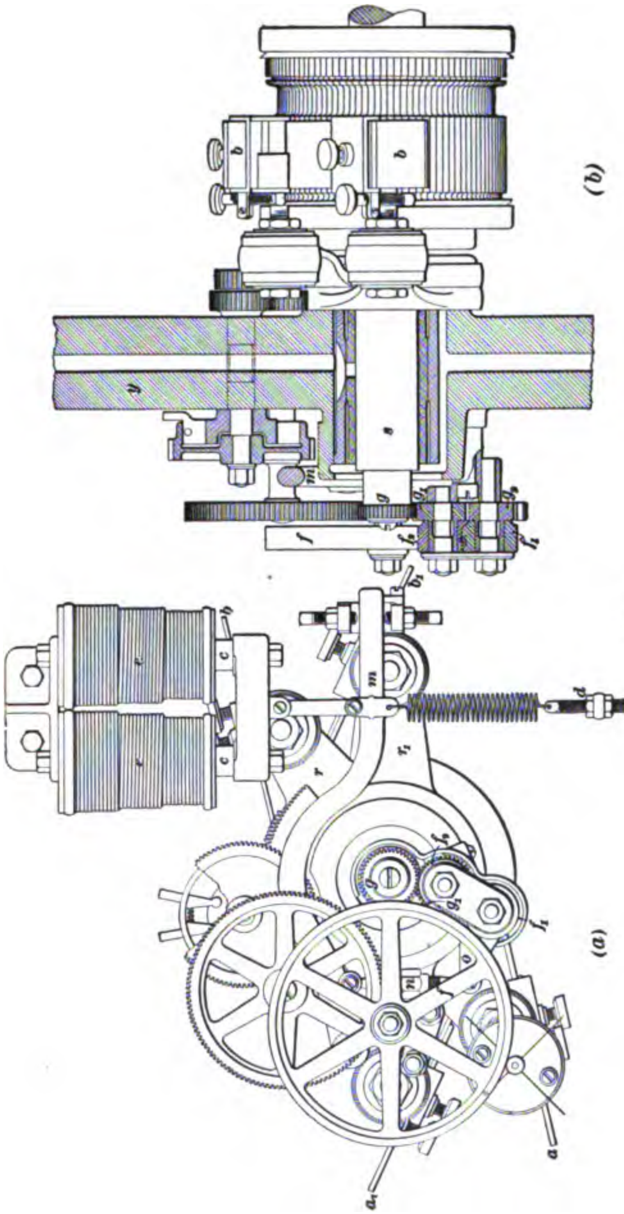


FIG. 1.

bearing ends of the brushes equal to about 3 commutator segments at light loads (low E. M. F.), and about double this at heavy loads (high E. M. F.). This variation in distance is accomplished by shifting the *back* brushes a_1 and b_1 of each pair a little faster than the front brushes a and b are shifted, so that the back brush gradually overtakes the front one, lessening the distance between them, in shifting from the heavy-load to the light-load position.

The electromagnet e is connected in series with the armature, field, and external circuit, and furnishes the power for regulating the current. The cores c, c of this electromagnet are free to move into or out of the coils, the attraction of the magnet being balanced by a tension spring provided with an adjustment at d. The lever arm m is raised by the electromagnet when the current increases, and is lowered when the current weakens. A small gear g on the end of the shaft continuously drives two friction-rollers f_1, f_2 in opposite directions by means of the gears g_1, g_2. The movement of the lever arm m presses the friction-wheel f, by means of the intermediate links n, o, against one or other of the friction-rollers, thereby turning the friction-wheel in a forward or backward direction. This motion is then communicated by means of gearing to the rocker-arms, producing the relative movement already referred to. The two positive and the two negative brushes are connected by short, flexible cables, so that the intervening coils on the armature are short-circuited. As the distance between the brushes increases, a further number of coils will be short-circuited; as these coils lie, however, in the neutral space, the effect of cutting them out is to neutralize their demagnetizing action, thereby increasing the E. M. F. of the dynamo. In order to facilitate adjustment, the brushes are set to a certain length, the amount of their projection from the holders being determined by means of a gauge. The regulator is fastened to one of the yokes y of the field. In the larger sizes of these machines, the friction-rollers are driven by a light belt from a small pulley on the end of the armature shaft, but otherwise operate in the same manner as

that described. These regulators are simple and reliable in action.

8. Standard Dynamos.—These machines have bipolar, consequent-pole, series-wound field-magnets of the type illustrated at *H*, Fig. 45, Part 2. The armature is of the ring type, and differs from that of the Wood machine only in the details of its construction. A single pair of brushes is used, which is shifted to vary the E. M. F. and to keep the current constant by a mechanism situated on the base of the machine. This mechanism is driven by a light belt from a small pulley fastened to the end of the armature shaft.

In these machines, the field-magnets themselves act as a controlling magnet, a short bar of soft iron pivoted in the center being placed between the tips of the pole-pieces on one side to act as a keeper. The tendency of this keeper is to move around until it is in a straight line between the two pole tips, but it is held at an angle to this position by the pull of a spring. Attached to this keeper is a lever, which is also attached to two *pawls*, or pointed strips of iron, hinged at one end and pointing in opposite directions. These two pawls are kept at a certain distance apart, but the attachment to the keeper is so arranged that when the keeper moves away from its normal position against the pull of its spring, the pawls move so that the points of both are lowered, and when the spring pulls the keeper away from its normal position, the points of both the pawls are raised.

These pawls are given a continuous back-and-forth movement by an eccentric driven by the belt from the pulley on the armature shaft, and between them there is a flat bar, notched or toothed on the edges, which is attached to the rocker-arm of the machine.

The method of regulation is, then, as follows: If the resistance of the external circuit decreases, the corresponding increase in the current strengthens the field-magnets, which causes the keeper to move away from its normal position against the pull of the spring. This lowers both the pawls, and the top pawl, which points *towards* the commutator,

catches in the teeth on the top edge of the flat bar which is attached to the rocker-arm, and as the pawl moves back and forth, the rod is pushed ahead (towards the commutator), thus shifting the brushes away from the neutral point. When the reduction in the difference of potential is sufficient to reduce the current to its normal value, the keeper returns to its normal position, lifting both pawls, so that neither catches on the teeth of the flat bar, which therefore becomes stationary. If the current is reduced below its normal value by an increase in the external resistance, the keeper is pulled away from its normal position by the spring, and the pawls are lifted still farther, until the lower pawl catches on the teeth on the under side of the flat bar. As this pawl points away from the commutator, its motion causes it to push the rod in the same direction, rocking the brushes *towards* the neutral point and increasing the difference of potential between them until the current is again at its normal strength.

9. Western Electric Dynamos.—In the smaller sizes these machines have bipolar, consequent-pole, series-wound field-magnets of the type illustrated at *I*, Fig. 45, Part 2, with drum-wound armatures; in the larger sizes the field-magnets are multipolar, with salient poles, and ring-wound armatures are used.

The machines are regulated to give a constant current by shifting the brushes, as in those previously described; the mechanism for shifting the brushes is driven by a belt from the end of the armature shaft, and controlled by a separate controlling magnet, as in the Wood dynamo. The controlling magnet throws into or out of gear or reverses a friction-clutch arrangement, which shifts the brushes forwards or backwards as the load is increased or diminished.

10. Excelsior Dynamos.—These machines have bipolar, salient-pole, series-wound field-magnets, and use ring armatures. The type of field-magnet used is similar to what the type illustrated at *D*, Fig. 45, Part 2, would become if the field cores, yoke, and spools on one side of the magnet were removed, leaving the pole-pieces covering

three faces of the armature. An iron arm projects from each pole-piece, forming the pole-pieces for a small armature, which is operated as a motor to shift the brushes of the machine. This small armature is geared to the rocker-arm, and the controlling magnet is so arranged that if the current in the machine rises above the normal, a portion of the current is shunted through the armature of this small motor, which causes it to turn in such a direction that the brushes are moved away from the neutral point, thus reducing the current.

At the same time, the motion of the rocker-arm operates a switch which cuts out some of the turns of the magnetizing coils, thus reducing the E. M. F. of the armature. It will be seen that this method of regulating the difference of potential between the brushes is a combination of the methods described in Arts. **4** and **5**.

If the current is decreased below the normal strength, the controlling magnet reverses the current in the armature of the small motor, so that it runs in the opposite direction and shifts the brushes towards the neutral point, at the same time cutting *in* some of the turns of the magnetizing coils, all of which brings the current back to its normal strength.

11. Ball Dynamos.—These machines are of a very peculiar construction. The magnetic circuit is represented in Fig. 2, from which it will be seen that two armatures are employed, each with an independent commutator. The field-magnet is arranged with only one pole-piece for each armature, as represented;

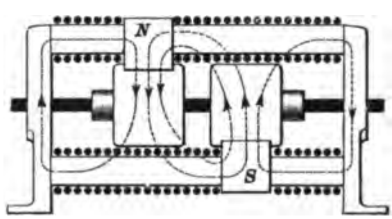


FIG. 2.

but as the lines of force must complete their circuit, they form irregular poles on the opposite side of the armature, the paths of the lines of force being represented by the dotted lines in the figure. The armatures are ring wound, and may each be used separately or connected in series.

In the larger machines of this type, the regulation is obtained by automatically shifting the brushes, the field-magnets of the machine itself acting as the controlling magnet, and also furnishing the necessary power. A circular opening is made in the magnetic yoke (on each end of the machine) of such size that the area of the magnetic circuit at that point is much reduced, which causes a leakage of the lines of force across the opening. Two iron segments are supported on a non-magnetic hub in this opening. Now, if these iron pieces were free to move, they would take up such a position in the opening as to make up as much as possible for the reduction in the area of the magnetic circuit, and allow the lines of force to pass directly through them. They are free to rotate about the hub to which they are attached, which revolves on ball bearings, but are prevented from taking up their natural position by a counterweight, which deflects them more or less, according to the strength of the field of the machine.

The brush-holder studs are connected directly to this movable part of the magnetic yoke, so that when the strength of the field increases, due to an increase in the current above the normal strength, this movable part is pulled around against the opposition of its counterweight until the brushes are shifted to the point where the current again becomes of normal strength.

OPEN-COIL ARMATURES.

12. Open-coil windings consist of a comparatively small number of coils, which are connected directly to the external circuit (through the commutator) when in the position where the E. M. F. generated in them is a maximum. (See Art. **20,** Part 2.)

As the coils move away from this position, they are connected in parallel with other coils, and are finally, when near the position where their E. M. F. is zero, disconnected entirely from the external circuit. These various connections

are made by the brushes and the commutator, by means which will be explained in speaking of the principal makes of machines of this type. The changes in the connections of the coils and the small number of coils used make the difference of potential between the brushes fluctuate, so that the current in the external circuit is *pulsating* in character. In speaking of it as a *constant* current, it is meant that the *average* current strength is constant.

PRINCIPAL OPEN-COIL CONSTANT-CURRENT DYNAMOS.

13. Brush Dynamos.—These machines use a disk-shaped ring-wound armature with projections on both sides of the ring, between which the coils are wound.

The magnetic circuit has four poles, but is really a consequent-pole, bipolar field-magnet, as will be seen from Fig. 3, which represents the field-magnet as seen from the top. This type of field-magnet is what that shown at *D*, Fig. 45, Part 2, would become if that part of each pole-piece which covers the cylindrical face of the ring were removed.

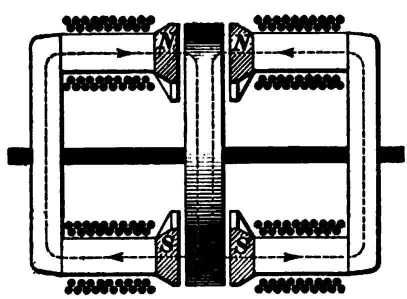


FIG. 3.

The armature winding of these machines consists really of a number of windings, each with a separate commutator. Each winding consists of four coils, arranged in two sets of two coils each. The two coils of each set are placed on opposite sides of the armature core, so that one coil is always in the same position relative to one pole-piece that the other coil is to the other pole-piece; this being the case, the E. M. F.'s generated in the coils are equal at all parts of their revolution, and they are permanently connected in series, so that they really act as one coil. The other set of coils belonging to the winding is placed on the core in the

same manner, but at right angles to the first set, so that when the coils of one set are under the center of the pole-pieces, that is, are in their most active position, the coils of the other set are in the neutral spaces, that is, in their least active position.

14. It will be seen that this arrangement of the two sets of coils corresponds to the arrangement of the two loops of wire described in Art. **15,** Part 2, and illustrated in Fig. 19, Part 2; the ends of each of the two sets of coils are connected to two opposite segments of a commutator just as there described, except that instead of each segment being a little less than ½ of the circumference, so that the brushes leave one pair of segments at the same time that they begin to bear on the other pair, in the Brush commutator each segment covers a little more than ½ the circumference, the segments of one pair being placed alongside the segments of the other pair, to allow for this extra length.

This is represented in Fig. 4, *a* and *a'* being the two segments connected to one set of coils, and *b* and *b'* being the two that are connected to the other set. It will be seen from this figure that each of the brushes (*1* and *2*) rests on one of the two opposite segments *b* and *b'*; but as the commutator revolves, each brush rests on one segment of *each* pair, *a'* and *b'* and *a* and *b*, where they overlap. Consequently, the coils connected to each pair of segments are connected in parallel with each other during a part of each half revolution.

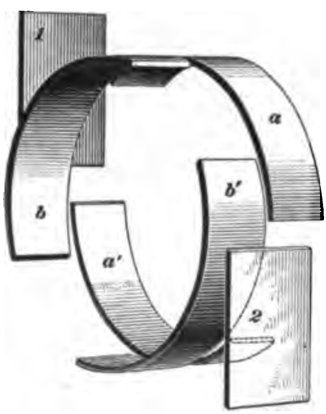


FIG. 4.

If this form of commutator with overlapping segments be applied to Fig. 19, Part 2, it will be seen that at the moment when the two loops of wire are thrown in parallel by each brush resting on two segments, the E. M. F. in the two

loops is not the same, that of the loop which had just before alone been connected to the brushes being higher than that of the other. A little later, at the moment when one of the loops is disconnected from the circuit by each brush passing from two segments to a single segment, the coil which is disconnected has a less E. M. F. than the other.

If the loops had little self-induction, this would result in the greater E. M. F. of the one loop sending a current around through the other loop against the E. M. F. generated in it, which current would not appear in the external circuit, and would therefore represent so much wasted energy.

This *local current* would evidently be greatest when the difference between the E. M. F.'s of the two coils is greatest, that is, at the moment when the two loops are connected in parallel, and at the moment one of the loops is disconnected from the brushes. Then, when the one loop is disconnected from the other, this local current would be suddenly broken, and this would result in sparking.

In the Brush machines, the self-induction of the coils is considerable, so that when two sets of coils are connected in parallel, the self-induction of the coil having the lower E. M. F. prevents this sudden rush of local current, and takes up its share of the output of the machine gradually.

At the same time, the parallel connection of the sets of coils is not broken until the E. M. F. of the set which is disconnected is enough lower than that of the other set so that it is furnishing practically none of the current output; hence, there is little sparking when it is disconnected.

15. As stated, the Brush armature winding is made up of two or more separate windings, the action of each being as already described.

Fig. 5 represents a Brush armature with two separate windings. In this figure, the pole-pieces are represented by the heavy dotted lines as they face the sides of the armature, as shown in Fig. 3. The segments of the two separate commutators are, for convenience, represented as concentric,

with the brushes resting on their edges; whereas, actually, they lie side by side, forming two separate commutators of the same diameter, each having four segments, and the brushes rest on their circumferences.

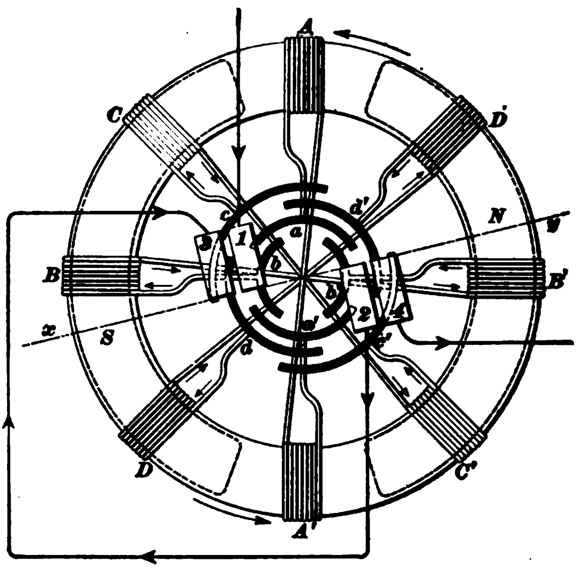


FIG. 5.

One winding consists of two pairs of coils *A A'* and *B B'*, located at right angles to each other, the coils of each pair being connected in series, as represented.

This winding is connected to its commutator, coil *A* to segment *a*, coil *A'* to segment *a'*, coil *B* to segment *b*, and coil *B'* to segment *b'*, as represented. Brushes *1* and *2* rest on this commutator, making contact on the line of maximum action *x y* of the coils. It will be seen that this line is not from center to center of the pole-pieces, but is moved ahead (in the direction of rotation, as indicated by the arrows) from this position by the armature reaction.

The second winding consists of two pairs of coils *C C'* and *D D'*, located at right angles to each other and half way between the coils of the first winding. These coils are

connected in series and to the segments of the second commutator, coil C to segment c, coil C' to segment c', coil D to segment d, and coil D' to segment d', as represented. Brushes *3* and *4* rest upon the segments of this commutator on the same line of maximum action of the coils.

Taking each winding separately, it will be seen that its two sets of coils pass through the following combinations: One set of coils only connected to the brushes; then the two sets, connected in parallel, both connected to the brushes; then one set only; then both sets in parallel; and so on.

The maximum E. M. F. occurs when the single set of coils is connected and is directly in the line of maximum action; the minimum occurs $\frac{1}{8}$ of a revolution ahead of this point, when both sets of coils are in parallel and are equally distant from the line of maximum action. (See Fig. 20, Part 2, and compare the accompanying text with the above.)

This being the case, it is evident that as the coils of one winding are half way between the coils of the other, *the maximum E. M. F. of one winding occurs at the same instant as does the minimum E. M. F. of the other.* On account of this, when the two windings are connected in series, the fluctuations of the current are much reduced.

This connection of the two windings is obtained by connecting the positive brush (*2*, Fig. 5) of one winding with the negative (*3*, Fig. 5) of the other, the external circuit being connected between the two remaining brushes (*1* and *4*, Fig. 5).

In the large sizes of these machines, three and even four separate windings are used, each with its commutator, and all connected in series. In the larger multipolar machines, each winding consists of two sets of coils, each set containing four coils, one for each pole-piece. The action is precisely the same as in the bipolar machine.

16. The regulation of the Brush machines is nearly automatic; that is, a machine will give *nearly* a constant current without any regulation whatever. This is due to the fact that the armature reaction increases so much with

any increase in the current that the line of maximum action is shifted farther ahead, which changes the relations of the various coils at the time when they are connected with, or disconnected from, each other or the external circuit.

This regulation is, however, not close enough for commercial working; so in addition, a resistance is placed in shunt to the magnetizing coils, which is varied by a controlling magnet in the main circuit, thus making the regulation very exact. (See Art. **41**, Part 2, and Fig. 43, Part 2.)

This resistance consists of a series of blocks of carbon—a material which has the property of lessening its resistance if subjected to pressure. In this case the pressure is obtained by the pull of the controlling magnet on its keeper, which forms the end of a lever that presses upon the carbon blocks. If the current in the external circuit increases, due to a lessening of the external resistance, the controlling magnet pulls on its keeper with greater force, thus increasing the pressure on the carbons, decreasing their resistance, and weakening the strength of the field-magnets, which reduces the E. M. F. of the armature coils until the current is again at its normal strength.

The shifting of the point of maximum action, due to the weakening of the field at light loads, causes a certain amount of sparking, which is remedied by slightly shifting the brushes. In the multipolar machines, this shifting is performed automatically by mechanism driven by a belt from a small pulley on the end of the armature shaft, and controlled by the controlling magnet, as in the closed-coil dynamos described.

17. Westinghouse Dynamos. — These machines, which are comparatively new, use a multipolar field-magnet with six salient poles, of the type illustrated at *C*, Fig. 49, Part 2. The armature coils are wound around eight projecting teeth on the armature core, there being, therefore, eight armature coils. With eight coils and six poles, it is evident that only two coils can be directly under any two pole-pieces at the same instant. This armature winding, as in the Brush

machine, is divided into two separate windings, each consisting of two pairs of opposite coils, and each connected to a separate commutator. The combination of connections of the various sets of coils is similar to that of the Brush machine; that is, the set of coils in the position of least action is disconnected entirely from the circuit, those near the position of maximum action are connected in parallel, and in series (by external connection of the brushes) with that set which is actually in the position of maximum action.

In this machine, a coil is in the position of least action when the projection on which it is wound is directly under a pole-piece, for when in this position all the lines of force from the pole-piece pass directly through the center of the coil, which therefore cuts none of the lines of force. As soon as the coil moves from this position, one side begins to cut the lines of force of the pole-piece it is moving away from; as it moves still farther, the *other* side of the coil begins to cut the lines of force of the pole-piece *towards* which it is moving, so that when half way between the two, both sides of the coil are cutting lines of force equally and at the maximum rate, and this is, therefore, the position of *maximum* action.

18. _ diagram showing the connections of the armature winding to the commutator of the Westinghouse machine is given in Fig. 6. As in Fig. 5, the two commutators are represented as concentric, though they are actually side by side on the shaft, and, as in the Brush machine, are situated on the end of the shaft outside one of the bearings, the leads to the commutator being brought out through a hole in the shaft, instead of being connected directly, as represented in the diagram.

The two pairs of coils A and A' and B and B' make up one winding, and are connected to one commutator, as represented. The two opposite coils A and A' and B and B' are connected in series by connections across the back of the armature core (not shown in the diagram).

The other winding is made up of the two pairs of coils

C and *C'* and *D* and *D'*, the coils of each pair being connected in series, as before.

It will be seen that each commutator is made up of twelve segments separated by a considerable width of insulating material (indicated by the solid-black parts). These twelve segments are connected together by cross-connecting wires in three sets (one for each pair of poles), of four segments each (one for each coil of the windings).

Instead of the segments overlapping as they do in the Brush machine, each brush is divided into two parts, which rest on the commutator at a distance apart equal to the length of one segment, as represented at *1 1'* or *2 2'*

Applying the statement made in Art. **17** to Fig. 6, it will be seen that coils *A* and *A'* are in the position of least

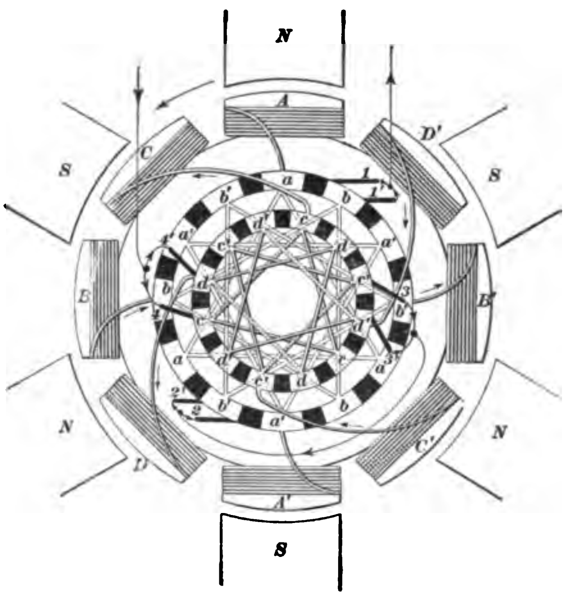


FIG. 6.

action, and are disconnected from the external circuit. The other set of coils of this winding, *B* and *B'*, is, however, in the position of maximum action, and is connected to the circuit through brushes *1* and *1'* and *2* and *2'*, which rest on

segments b and b', respectively. Of the second winding, each set of coils C and C' and D and D' is equally distant from the position of maximum action, and these two sets are therefore connected in parallel with each other through brushes *4* and *4'*, which rest on segments c and d, and brushes *3* and *3'*, which rest on segments c' and d', and are connected in series with the set of coils B and B' by the external connection between the two sets of brushes *2* and *2'* and *3* and *3'*.

To follow out the changes in the connections of the coils, consider that the armature is moving in the direction indicated by the arrow.

As coils B and B' move away from their position of maximum action, brushes *1'* and *2'* are disconnected from segments b and b', and as the armature moves, finally come into contact with segments a and a', thus throwing the two sets of coils A and A' and B and B' in parallel. At the same time, brushes *4* and *3* being disconnected by the insulating segment from segments c and c', coils D and D' only of the second winding are connected to the circuit through brush *4'* and in series with the coils of the other winding (now connected in parallel) through brush *3'* and its connection with brushes *2* and *2'*, coils C and C' being entirely disconnected.

It will be seen that these successive combinations of coils are precisely the same as take place in the Brush machine, except that each combination takes place six times in each revolution, instead of twice, which is due to the multipolar field. The regulation of this machine is entirely automatic. The field-magnets are separately excited, the current being furnished by a separate constant-potential dynamo, which gives a constant magnetizing force; but the strength and distribution of the resulting field are dependent on the armature reaction, which is so proportioned that any excess of current over the normal so reduces and distorts the field that the E. M. F. generated in a winding during the time that it is connected to the brushes is reduced until the current is again at its normal strength.

19. Thomson-Houston Dynamos.—These machines have bipolar, series-wound, salient-pole field-magnets, of the type illustrated at *K*, Fig. 45, Part 2. The completed armature is very nearly spherical in shape, and the pole-pieces are bored out accordingly, so that they almost entirely enclose the armature.

In the older machines, the armature is drum-wound, although the core is a ring, but in the newer machines, a ring winding is used; in either case, three separate coils, or sets of coils, make up the winding. One end of each of these coils (or sets of coils) is connected to a commutator segment, all the other ends being joined together.

The commutator has three segments, each covering nearly $\frac{1}{3}$ of the circumference, the balance being made up by the air-spaces which separate the segments.

Two positive and two negative brushes are used, those of each pair resting on the commutator at two points at a distance apart equal to one-half a commutator segment, that is, nearly $\frac{1}{6}$ the circumference, when the machine is giving its greatest E. M. F.

20. A diagram of the connections, etc., of the drum-wound armature is shown in Fig. 7. *A A'*, *B B'*, and *C C'*

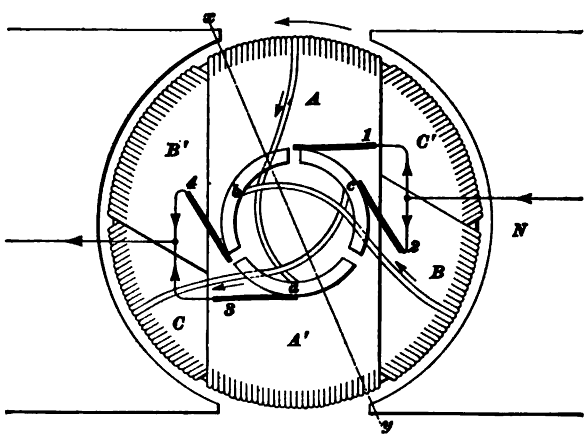


FIG. 7.

are the three coils, wound on the core $\frac{1}{3}$ of the circumference

apart. One end of each of the coils is joined to a metal ring (not represented in the figure) on the back of the armature, which forms a common connection for the three. The other ends are joined to the commutator segments, that of $A\ A'$ to segment *a*, that of $B\ B'$ to segment *b*, and that of $C\ C'$ to segment *c*, as represented; *1* and *2* are the negative, and *3* and *4* the positive, brushes. Brushes *2* and *4* are usually called the *primary* brushes and *1* and *3* the *secondary* brushes, to distinguish them.

From the diagram (Fig. 7) it will be seen that coil $A\ A'$, though half way between the pole-pieces, is partly active, since the neutral line is shifted forwards by armature reaction, as indicated by the line $x\ y$. This coil $A\ A'$ is connected in parallel with coil $B\ B'$ by the two positive brushes, and the two are in series with coil $C\ C'$. If the armature be considered as moving in the direction indicated by the arrow, it will be seen that as coil $A\ A'$ gets to the position of least action, it is disconnected from the circuit by segment *a* passing out from under brush *3*, leaving coil $B\ B'$ and coil $C\ C'$ in series. However, as the distance between brush *3* and brush *2* is only slightly greater than the span of one segment, coil $A\ A'$ is almost immediately connected in parallel with coil $C\ C'$, as segment *a* passes under brush *2*, making the following combination: Coil $B\ B'$ in series with coils $A\ A'$ and $C\ C'$ in parallel.

As the rotation of the armature continues, coil $C\ C'$ is disconnected from the negative brush *1* and connected to the positive brush *4*, being thus thrown in parallel with coil $B\ B'$, the two being then in series with coil $A\ A'$.

Completing the half revolution, coil $B\ B'$ is disconnected from the positive brush *3*, and is joined in parallel with coil $A\ A'$ by the two negative brushes *1* and *2*, leaving coil $C\ C'$ connected to the positive brushes.

Further rotation of the armature repeats this series of connections; that is, during every half revolution, one of the coils ($A\ A'$ in the preceding paragraphs) is first in parallel with the coil *behind* it, then momentarily disconnected from the circuit, then connected in parallel with the coil

ahead of it, then connected in series with the other two, which are then in parallel.

From the diagram (Fig. 7) it will be seen that when a coil is disconnected from one set of brushes, it is very nearly in the position of least action, and the coil with which it was just before connected in parallel has the higher E. M. F. of the two. As explained in Art. **14,** the self-induction of the coil prevents the higher E. M. F. of the other sending a current through it in opposition to its own E. M. F. at the time when they are connected in parallel; in fact, when the coil is disconnected from its mate, it is still supplying some of the current, so that there is a spark at the brushes.

21. The regulation of this machine is effected by varying the distance between the two brushes of each set, the primary brush being moved back and the secondary ahead. This movement of the brushes decreases the distance between the primary brush of one set and the secondary of the other. Now, as when in the position shown in the figure (Fig. 7), this distance is only slightly greater than the span of one commutator segment, it is evident that lessening this distance will allow of one segment being under *both* one of the positive and one of the negative brushes during a part of a revolution, which *short-circuits* the armature, reducing the difference of potential between the brushes (momentarily) to zero.

As the field-magnets are in series with the armature, their great self-induction prevents the strength of the current from falling to zero, its fluctuations being comparatively small. At the same time, the self-induction of the armature coils prevents any excessive flow of current from one to the other through this short circuit; for, there being two places where the short circuit occurs, i. e., between brushes *1* and *4* and *2* and *3*, and there being three commutator segments, it is evident that six short circuits occur during every revolution, and if the armature is revolving at 850 revolutions per minute, there are $6 \times 850 = 5{,}100$ short circuits every minute, so that each lasts only an extremely short time.

As the distance between the brushes of a set is increased, each short circuit is kept up for a slightly longer time. It will be seen that this momentary reduction of the difference of potential between the brushes to zero reduces its effect in sending a current through the circuit, although its maximum value is not much reduced; so that by shifting the brushes at the proper time, the current in the external circuit can be kept at a constant strength, in spite of variations in the external resistance.

This shifting of the brushes is done automatically by the following apparatus: The primary and secondary brushes are mounted on separate rocker-arms, which are connected together by a system of levers, so that when the primary brushes are shifted back, the secondary are moved ahead. The amount of movement of the secondary brushes is very little, being for the purpose of following the line of maximum action, which moves ahead slightly at light loads (low E. M. F.). A large magnet attached to the frame of the machine has attached to its keeper a lever, which is connected to the rocker-arm that carries the primary brushes, so that when the keeper of the magnet is pulled up, the primary brushes are shifted back and the secondary ahead, thus reducing the effective difference of potential between the brushes, as explained. The current for operating this regulating magnet is supplied by the main current, but it is not continually in circuit, being cut in or out, as occasion requires, by a controlling magnet, which is placed on the wall of the room at some convenient place.

22. Fig. 8 is a diagram of the connections used in this apparatus. *R* represents the regulating magnet and *K* its keeper, which is connected to the rocker-arms by a lever (not shown), as described. *C*, *C* represent the coils of the controlling magnet, which are stationary, and *D*, *D* represent the cores of this magnet, which are movable. Their weight is partly counterbalanced by the spring *s*, the tension of which is adjusted by means of the nuts at *N*. Attached to these cores is a contact point, which touches a

stationary contact piece at *B*. The connections being as represented, + being the positive terminal of the dynamo, it is evident that when the two contact points at *B* are touching, the regulating magnet *R* is short-circuited, the current flowing from + to p^2, thence to P^2, thence through the contact points at *B* to *P*, thence through coils *C*, *C* to P^1, and out to the line. Now, if this current exceeds a certain strength, the pull of the coils *C*, *C* on the cores *D*, *D* becomes sufficient to raise them, breaking the contact at *B*. This forces the current around from P^2 through the regulating magnet *R* to *P*, thence to P^1, where it passes out to the line as before. The regulating magnet then attracts and pulls up its keeper *K*, which in moving shifts the brushes and reduces the current as described.

When the current is reduced to its normal value, the cores of the controlling magnet descend, and contact is made at *B*, which short-circuits the regulating magnet, and allows its keeper to drop. This shifts the brushes again so as to increase the current. This action is kept up, so that the cores of the controlling magnet and the brushes of the machine are continually in slight motion. In order to prevent the self-induction of the regulating magnet causing a serious spark at *B* when the contact is broken, a shunt of high resistance is permanently connected around the break at *B*, as represented at *r*. This self-induction is produced in the regulating magnet *R* whenever the circuit is opened at *B*, for this suddenly diverts the main current through the regulating magnet, whose momentary self-induction opposes the current, forcing it along by way of p^2, P^2, and the resistance *r* to the line. If the resistance were not there, the

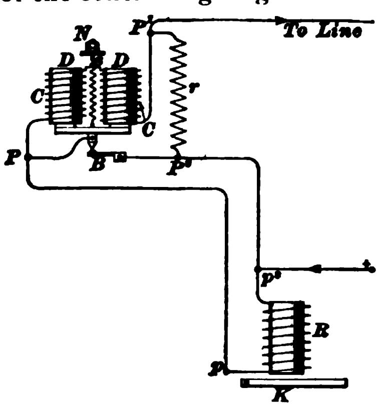


FIG. 8.

current would cross the air-gap at B, making a destructive spark.

The space between the ends of the commutator segments being small, some device is necessary to prevent the spark which occurs when a segment passes from under one of the secondary brushes from continuing to pass from segment to segment, for that would permanently short-circuit the machine. This device consists of a small rotary blower, which is situated between the commutator and the bearing. This blower is so arranged as to deliver a puff of air right at the end of the secondary brushes at the moment that the spark occurs, so that it is immediately broken and does no damage.

The adjustment of the commutator, brushes, air-blast, etc., of this machine requires considerable attention in order that the machine should run well. The manufacturers supply printed matter with each machine, giving full particulars of these operations, hence they need not be taken up here.

THE OUTPUT OF CONSTANT-CURRENT DYNAMOS.

23. From the nature of the output, the heat losses in constant-current dynamos are practically constant at all loads. In some of the open-coil machines, the local currents which circulate in the coils may be of greater strength than the current in the external circuit, at light loads, so that the heating of the armature may be even greater at light loads than at full load. It is evident, however, that the heating is not the factor which limits the load, nor is the sparking, since the machine must be so designed that the sparking is the same at all loads. The factor of the load which varies is the E. M. F., so that when this has reached its highest value, any further increase in the external resistance can only reduce the current, since the E. M. F. can not increase farther. The maximum E. M. F. which the machine can give is then the limit of its output.

Constant-current machines may be rated according to their output, expressed in kilowatts (1 kilowatt being one thousand watts), as are constant-potential machines; but as they are almost invariably used for operating *arc lamps*, they are usually rated according to the maximum number of lamps for which they can supply current. The strength of the current most used is from 9.5 to 10 amperes, 9.6 being the standard adopted by many manufacturers. With this current, each arc lamp requires from 45 to 50 volts. All lamps being connected in series, this makes the maximum E. M. F. of, for example, an 80-light dynamo $80 \times 50 = 4{,}000$ volts. Machines are built of 150 lights capacity, but the sizes most generally used have a capacity of from 50 to 80 lights.

Almost all the regulating devices used are practically independent of the speed, so that they will maintain the current constant when the speed varies somewhat, if the variations are not too sudden. Any reduction in the speed, however, reduces the maximum E. M. F. and output which can be obtained, and, conversely, an increase in the speed will increase the possible output.

ALTERNATING-CURRENT DYNAMOS.

DEFINITIONS.

24. The definition of an alternating current is given in Art. **13,** Part 2. In speaking of alternating currents, each reversal of the current, that is, each increase of the current from zero to its maximum, and the decrease to zero again, is called an **alternation.** In the case of a simple loop of wire rotating in a magnetic field, the current in the loop goes through one *alternation* in each half revolution; in a complete revolution, it passes through two alternations—one in one direction and one in the contrary.

If the rotation is continued, this process is repeated for every revolution, so that an alternating current is made up of a number of repetitions of a pair of opposite alternations.

This pair of alternations is called a **cycle.** The number of cycles which occurs in a given time (usually one second) is called the **frequency,** so that if the simple loop referred to above is rotated at the rate of 60 revolutions per second, the frequency of the alternating current generated would be said to be 60, that is, 60 cycles per second.

In treating of alternating currents, the graphical method of representing the value of the E. M. F., or current, explained in Arts. **12** and **13,** Part 2, is much used. It is only necessary to represent one cycle, since under similar conditions they are all alike, and for convenience, the length of one cycle is taken to represent 360°, whatever may be the length of time required to complete it. Different parts of the curve may then be said to be so many degrees apart; for example, if the base line *A E* in Fig. 14, Part 2, is taken as 360°, each division will then represent 30°, since there are twelve divisions, and any two succeeding zero-points, as *A* and *C* or *C* and *E*, will be 180° apart, or a zero-point and a maximum point, as *A* and *B*, are 90° apart.

Further, any point on the curve may be said to be so many degrees ahead or behind some other point. For example, in this same figure, point *C* is 180° *behind* point *A*, because point *C* represents a later period of time than does point *A*, and is 180° *ahead* of point *E*, because it represents an earlier period of time.

ALTERNATORS.

25. The current in the separate conductors of a direct-current armature is naturally alternating; for when the conductors pass over from one pole-piece to another, the direction of the current in them is reversed. It is often necessary to use alternating currents in the external circuit, and when this is the case, there is substituted for the commutator which is used for the purpose of changing the alternating current of the armature conductors to a direct current for the external circuit, a pair of collector rings, which make continuous contact between the ends of the

armature winding and the brushes connected to the external circuit. (See Fig. 38, Part 2.)

The principle of the winding of alternating-current dynamos (commonly called **alternators**) is the same as that of direct-current machines, and either a ring or a drum winding may be used; but in order to get the best results, it is necessary to use a different method of connecting and locating the coils of the winding.

If a single coil of wire is wound on a ring core, and the core is rotated in a magnetic field, it is evident that if the coil occupies a space on the core greater than the width of the neutral space (see Art. **21**, Part 2), there will be two points in each revolution where a part of the coil is under *each* pole-piece, as represented in Fig. 9. Under these circumstances, the E. M. F. generated in that part of the coil under one pole-piece is opposite in direction to that generated in the part under the other pole, as represented by the arrow-heads, so that they neutralize, or partly neutralize, each other, until the coil has moved entirely out from under one pole-piece.

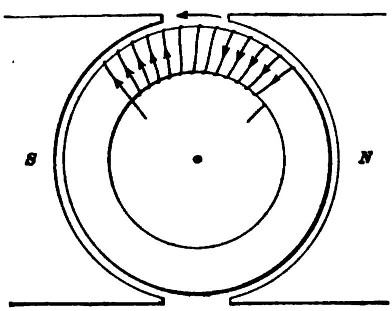


FIG. 9.

In order to prevent this opposition of the E. M. F.'s generated, it is necessary to make the coil no wider than the neutral space. Now, if the pole-pieces cover a large part of the surface of the armature, as is the case in the direct-current machines described, the coil must be very narrow, so that only a small part of the surface of the core is utilized. To remedy this, the pole-pieces of alternators are made narrow, usually so that the width of the neutral spaces is equal to the width of the fields. A coil may then be wound on the core equal in width to the width of the neutral space (or of the field, since these are equal), and there will be no opposition of the E. M. F.'s when the armature is rotated.

As the armature is rotated, the coil enters and leaves the field gradually; that is, first one conductor moves into the field and becomes active, then the next, then the next, and so on until the entire coil is in the field, when it moves out in the same manner. On this account, although the field is practically of uniform strength, the *total* E. M. F. of the coil rises gradually from zero, when it is wholly in a neutral space, to a maximum when it is wholly in one field, then falls gradually to zero again when in the other neutral space. Thus, the graphical representation of the values of the E. M. F. of such a coil at any instant would correspond with those given for the single loop in Art. **12,** Part 2.

26. If only a single coil is wound on the core, and its width is confined to that of the neutral space, only a small part of the surface of the core will be covered; but it is evident that another coil of equal width may also be wound on the core, directly opposite to the first.

This second coil will then enter or leave one field at the same time that the first is entering or leaving the other field, and with the same velocity, so that if the number of turns in the two coils is the same, they will have equal E. M. F.'s generated in them at any instant.

This being the case, the two coils can be connected in series, so that their E. M. F.'s will add together. Fig. 10 represents a ring-wound armature rotating in a bipolar field, with two opposite coils, each equal in width to the width of the neutral space, which is equal in width to the field. These two coils are connected in series, and to the two rings of a collector (shown for convenience as being concentric) on which bear two brushes B and B_1, between which an external circuit may be connected.

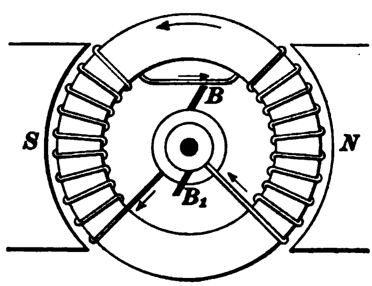


FIG. 10.

In this case, as in the simple loop, the E. M. F. (and the

resulting current) passes through one complete cycle during each revolution, so that the frequency is equal to the number of revolutions per second. The frequency of the alternating currents used for lighting is usually 125, although, recently, lower frequencies, down to about 60, have been adopted. It is evident that it would be very difficult to run an armature in a bipolar field at a number of revolutions per second equal to even the lower of the above frequencies, and for this reason it has been necessary to use multipolar fields for alternators.

With a multipolar field, the widths of the neutral spaces and of the fields are about equal in the best machines, and a number of coils, each equal in width to the width of a neutral space, is wound on the core, the number of coils being made equal to the number of poles, and arranged, as in the bipolar machine described, so that each coil is in the same part of a field or neutral space at the same instant.

It is evident that the E. M. F. of each coil passes through one complete cycle during the time that it is passing under two successive poles. This being the case, the frequency is then equal to the revolutions per second multiplied by the number of *pairs* of poles.

For example, in a ten-pole machine running at 1,500 revolutions per minute, the frequency is

$$\frac{1,500}{60} \times \frac{10}{2} = 125.$$

27. For these multipolar machines, ring windings are seldom used in this country. One of the commonest types of alternators is shown in Fig. 11. This machine is provided with eight radial poles and eight coils on the armature, giving a style of winding in common use for machines used on lighting circuits. In Fig. 11, the coils C are shown bedded in the slots p on the periphery of the iron core P, which is built up of thin iron stampings. These coils are heavily taped and insulated and are secured in place by hardwood wedges w. This makes a style of armature not easily injured, and the use of the dovetailed slots and wooden

wedges does away with the necessity of band wires. It is necessary that the space between the two halves of any one coil be made about equal to the width of the field, as represented in Fig. 11; for, if this were not the case, a part of

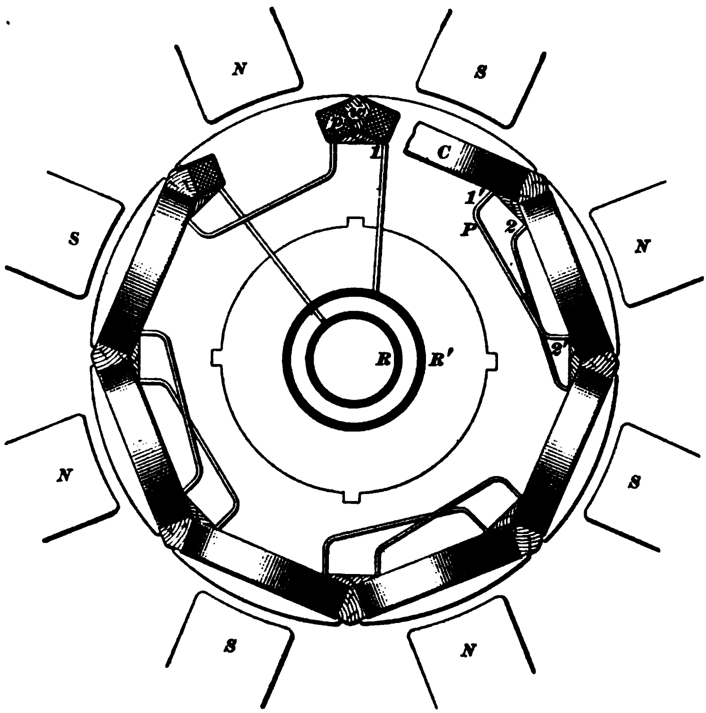


FIG. 11.

each of the two halves would be in the same field at the same time, which would cause the E. M. F.'s generated to oppose each other.

28. Alternators are generally required to furnish a high voltage, and, in consequence, the armature coils are usually connected in series. Care must be taken, in connecting up such windings, to see that the coils are so connected that the E. M. F.'s do not oppose one another. By laying out a diagram of the winding, the manner in which the coils must be connected will be easily seen. This has been done

in Fig. 12, which shows diagrammatically the winding of the armature in Fig. 11. The coils are represented by the heavy sector-shaped figures, and the connections between

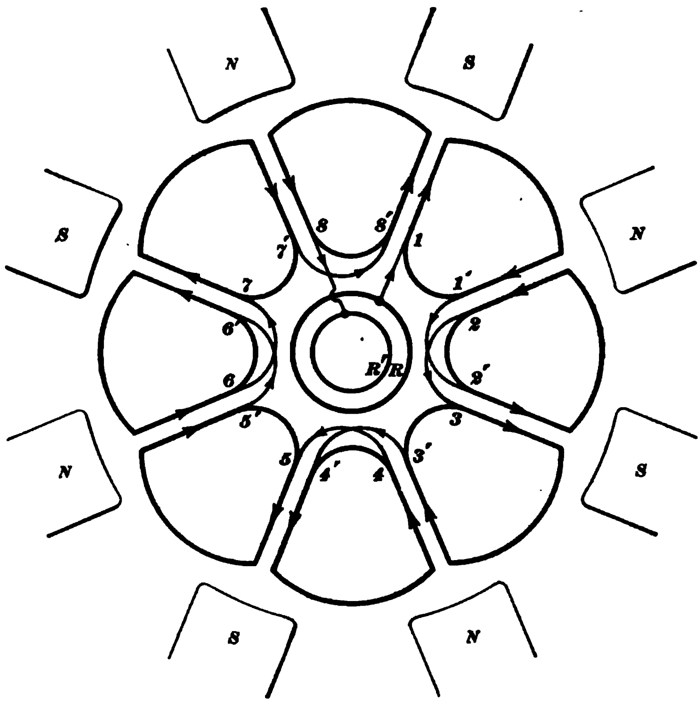


FIG. 12.

them by the lighter lines. The circles in the center represent the collector rings of the machine, and the radial lines that part of the coil which lies in the slot, that is, the part in which the E. M. F. is generated. The circular arcs joining the ends of the radial lines represent the ends of the coils which project beyond the laminated armature core. The drawing is made to show the coils at the instant the conductors in the slots are opposite the centers of the pole-pieces. At this instant, the E. M. F. will be assumed to be at its maximum value, and we will suppose that the direction of rotation is such that the conductors under the north poles have their E. M. F.'s directed from the back of the

armature towards the front. These E. M. F.'s will be denoted by an arrow-head pointing towards the center of the circle, since the inner end of the radial lines represents the front or collector-ring end of the armature. The E. M. F.'s in the conductors under the south poles must be in the opposite direction, or pointing away from the center. After having marked the direction of these E. M. F.'s, it only remains to connect the coils up so that the current will flow in accordance with the arrows. Starting from the collector ring *R* and passing through the coils in the direction of the arrows, it is seen that the connections of every other coil must be reversed; i. e., if *1*, *1'*, *2*, *2'*, etc., represent the terminals of the coils, *1'* and *2'* must be connected together, also *2* and *3*, and so on. The end *8* is connected to the other collector ring, and the winding thus completed. The connections of such a winding are quite simple; but if not connected with regard to the direction of the E. M. F.'s, as shown above, the armature will fail to work properly. For example, if *1'* were connected to *2*, *2'* to *3*, and so on around the armature, the even-numbered coils would exactly counterbalance the odd-numbered ones, and no voltage would be obtained between the collector rings. Of course, in this case, all the coils are supposed to be wound in the same direction, as is nearly always done in practice. The connections in the diagram, Fig. 12, are shown between the coils in Fig. 11. It should be noted that this constitutes an open-circuit winding; that is, the winding is not closed on itself, like that of a continuous-current drum or ring armature. A large number of alternator windings are of the open-circuit type, which is better adapted for the production of high voltages, because it admits of a larger number of turns being connected up in series.

29. Alternators are usually constructed to give a constant potential, and are generally compound wound for this purpose; but instead of a shunt winding, separate excitation is almost invariably used, a small constant-potential direct-current dynamo furnishing the necessary current.

This small dynamo is sometimes coupled directly to the end of the shaft of the alternator, but more usually belted to a pulley on that shaft.

The series coils of the field-magnets are excited by the main current of the alternator, just as in direct-current machines. As the alternating current could not be used directly for this purpose, a commutator is used, which changes the alternating current into a direct but pulsating current, in which form it is used to excite the series coils.

This commutator has as many segments as there are poles, but alternate segments are connected together, making practically a two-part commutator.

Two brushes rest upon this commutator at opposite points, and are so adjusted that they rest on two adjacent segments only at the moment that the E. M. F. of the armature winding is zero, so that the alternating current is changed to a pulsating current, just as described in Art. **14,** Part 2.

30. If the series coils alone were connected between these brushes, their self-induction would oppose both the rise and fall of the current, and would therefore cause sparking at the commutator; hence, a resistance coil, so wound as to have very little self-induction, is connected in parallel with the series coil, which so acts as to steady the current through the series coils and prevent the sparking at the commutator, in addition to providing a means for varying the degree of compounding of the series field. In some machines, a revolving shunt is connected across the terminals of the rectifier, thus cutting down the current to be rectified and thereby decreasing sparking.

This circuit through the series coils being in series with the armature winding, it forms a loop in that winding, and may be connected in at any convenient place; a point in the winding about half way between the ends which are connected to the collector rings is usually taken.

This is represented in Fig. 13, which is a diagram representing a 10-pole alternator, with a drum-wound armature of 10 coils, all connected in series. The beginning of coil *1* and that of coil *10* are both connected to one of the collector rings R, R, on which bear the brushes B and B_1, which are connected to the line terminals T and T_1, as represented. Coil *5* is not connected directly to coil *6*, but its

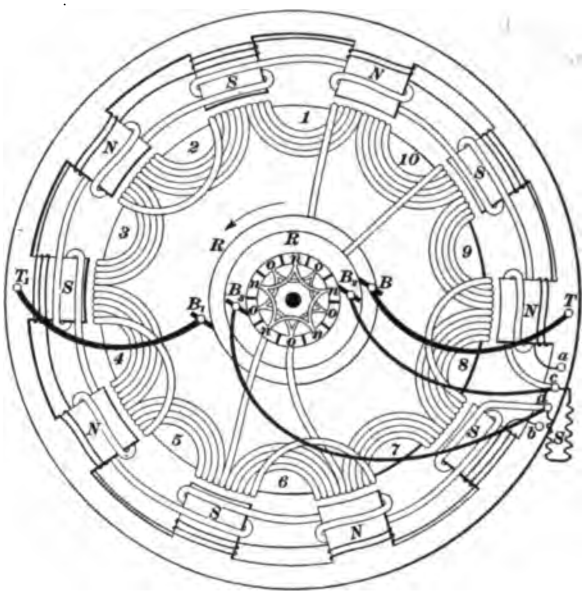


FIG. 13.

end is carried to one of the sections *n*, *n*, *n*, *n*, *n* of the commutator, these sections being all connected together as represented.

The end of coil *6* is connected to one of the rest of the sections *o*, *o*, *o*, *a*, *o* of the commutator, these being also all connected together.

At opposite points on this commutator rest two brushes B_2 and B_3, which are connected to the terminals *c*, *d* of the series winding on the fields. To these terminals the

resistance S is also connected, it being in parallel with the series coils.

The permanent excitation of the machine is supplied by a separate direct-current dynamo, as stated, which is connected to the terminals a, b.

In the position shown, the armature coils are most active, and the brushes B_2 and B_3 rest upon the middle of the commutator segments. At this instant, the path of the current flowing is as follows: Entering at terminal T, it passes through brush B to the inner collector ring, then through coils *10*, *9*, *8*, *7*, and *6* of the armature winding, then to one of the commutator segments marked o, and through brush B_3 to terminal d of the series field coils. Here it divides between these series coils and the resistance S, and reunites at terminal c, from whence it passes through brush B_2 to one of the commutator segments marked n, then through coils *5*, *4*, *3*, *2*, and *1* of the winding to the outer collector ring, then through brush B_1 to terminal T_1, and out through the external circuit.

As the armature revolves, bringing the coils into the neutral spaces, its current falls to zero. At this point, the brushes B_2 and B_3 pass from segments n and o to segments o and n, respectively, so that when the coils enter the fields again, and the current flows in the opposite direction through them, the direction of the current through the series winding is not reversed, but remains in the same direction as before.

It will be seen that the difference of potential between brushes B_2 and B_3 is only that due to the drop in the series coils and the resistance, which are in parallel. The difference of potential, therefore, between either of these brushes and one of the main brushes is practically the same, being equal to $\frac{1}{2}$ the total E. M. F. generated in the coils.

The above arrangement is that generally used in this country, although the type of the field-magnets and the details of construction vary considerably in the different machines.

MULTIPHASE ALTERNATORS.

31. The **phase** of an alternating current refers to the period of time at which it is at some particular point of its cycle; this term is generally used in comparing two or more different alternating currents. For example, if two alternating currents of the same frequency arrive at similar points in their cycles, the maximum or the zero-points, for instance, at the same instant, the two currents are said to be *in phase;* while if one current does not arrive at its maximum value at the same instant that the other does, the two currents are said to *differ in phase.*

The amount of this difference can be expressed in degrees, just as is the difference between any two points in the cycle of a single alternating current. (See Art. **24.**) Thus, if of two alternating currents, one reaches its maximum value at the same instant that the other is zero, they differ in phase by ¼ cycle, or 90°, and every point in the cycle of one current is 90° ahead of (or behind) the similar point in the cycle of the other current.

32. The alternators which we have been considering have a single winding and furnish only one current; for this reason, when it is desired to make a distinction, these machines are called **single-phase** alternators, and their current a single-phase current. The word *monophase* is also used to express the same meaning. For certain applications, alternators are provided with several windings, so arranged as to each give an alternating current differing in phase from the others. Such a machine is called, in general, a **polyphase** or **multiphase** alternator. Those in general use have either two or three separate windings, and are called **two-phase** or **three-phase** alternators, as the case may be.

Two-phase armatures can be considered as the windings of two single-phase machines mounted on one core, the two windings being separated 90° in the case of a two-pole machine. That is, when a coil of one winding would be directly under a pole, the corresponding coil in the second

winding would be midway between that pole and the next.

The two currents can be collected in two ways, namely: (1) by means of four collector rings, and (2) by means of three collector rings. To illustrate the former case, Fig. 14 may be referred to. This represents the two windings of a

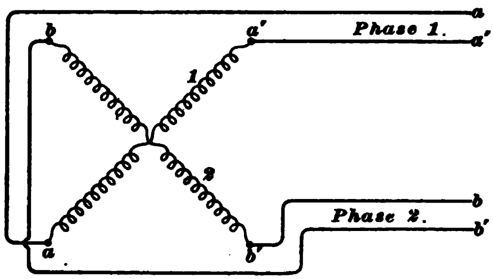
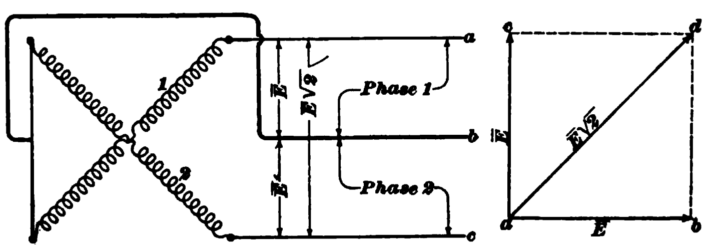


FIG. 14.

two-phase machine in a two-pole field. A displacement of 90° between the two currents calls for a similar mechanical displacement between the two windings. If four wires are used, the two circuits are independent of each other. The windings are represented by coils *1* and *2*, connected to the collector rings *a*, *a'* and *b*, *b'*. These windings, as was stated, have no electrical connection with each other and connect to two distinct circuits.

33. Sometimes, instead of using two distinct circuits with four collector rings, a common-return wire is employed,



(*a*) FIG. 15. (*b*)

as indicated in (*a*), Fig. 15. Here one end of each of the phases is joined to a common-return wire, and but three

collector rings are necessary. If $\overline{E}$ represents the E. M. F. generated per phase, the voltage between *a b* and *b c* will be $\overline{E}$, while that between *a c* will be $\overline{E}\sqrt{2}$. This will be understood by referring to (*b*), Fig. 15, the E. M. F. between *a* and *c* being the resultant of the two E. M. F.'s $\overline{E}$ at right angles to each other.

34. In some two-phase machines, the armature is wound with the equivalent of a series-path continuous-current winding, and four collector rings and independent circuits are then required to avoid short-circuiting portions of the armature. If a closed-coil continuous-current winding, as is represented in Fig. 16, is used in a two-pole field, a single-phase alternating current can be obtained by connecting two collector rings to opposite points of the winding, as at *1* and *3*. Connecting two *opposite* points will give the highest E. M. F. that can be obtained in this manner. If on the same armature we make connection to two other opposite points *2* and *4*, situated midway between *1* and *3*, we shall have in circuit *2′–4′* a single-phase alternating current differing in phase by 90° from that in circuit *1′–3′*. To obtain a three-wire two-phase circuit from this sort of winding, it is evident that there could be no combination of the indicated circuits made, as a portion of the winding would be short-circuited thereby. Instead, three of the four wires are used, as *1′*, *2′*, and *3′*. In this case, the two phases are *1* and *2* and *2* and *3*. Taking the E. M. F. per phase in the first instance to be E, in the latter case its value would be $\frac{E}{\sqrt{2}}$. The E. M. F. across the two outside wires *1* and *3* would be equal to E. The current in the common-return wire making connection at *2* will be $\sqrt{2}$ times that in each of the outer wires.

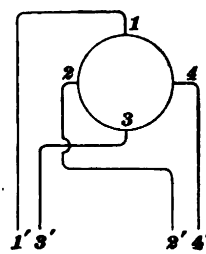


FIG. 16.

The graphical representation of these two currents shows that their sum at any instant is never as much as twice the

maximum of one of the currents; this is represented in Fig. 17.

In this diagram, *1* and *2* are the curves of the two currents, their difference in phase being 90°. It will be readily seen that there are parts of the cycle when the two currents are equal in value, but in opposite direction, as at 135° and 315°, and their sum at these points is then zero. At points

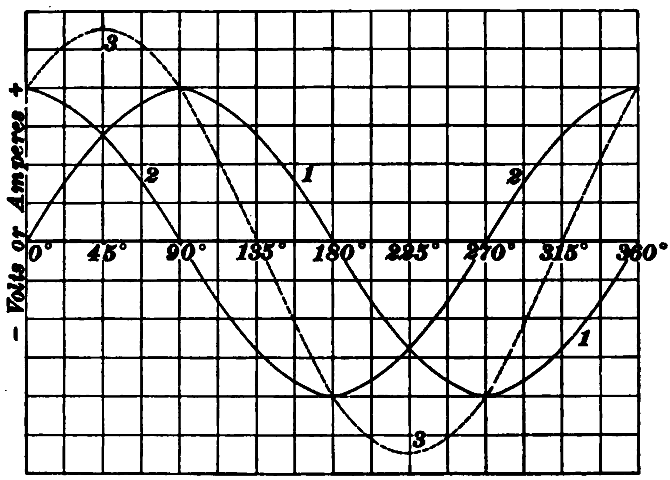


FIG. 17.

90° from these, the currents are again equal, but in the same direction, so that their sum is a maximum. Between these points their sum varies, its value at any instant being indicated by the dotted curve *3–3*. It will be seen that the maximum point of this curve is about 1.4 times the maximum of either of the others, and occurs 45° ahead of the maximum of the one and 45° behind the maximum of the other; consequently, the sum of the two curves which differ 90° in phase is a similar curve which differs in phase 45° from each of the others.

35. In three-phase machines, three windings are used, giving three separate currents differing 120° in phase;

these are graphically represented in Fig. 18. It will be seen from this diagram that at any instant *the amount of current flowing in one direction is equal to the amount flowing in the opposite direction.* For example, at the moment when the current represented by curve *2* is at its maximum, as at 90°, the other two currents are in the opposite direction, and are each equal to half their maximum value; their sum is then equal and opposite to the

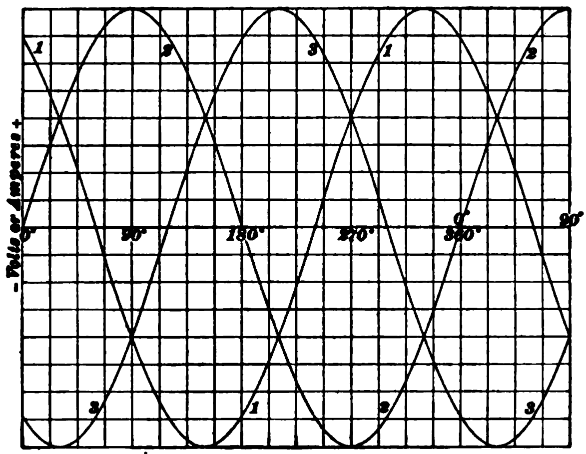


FIG. 18.

other current. At 180°, when curve *2* is at zero, the other two curves indicate that the currents are equal in value and opposite in direction. At any other part of the cycle, the above statement still holds true, as will be seen by measuring off with a pair of dividers the vertical distances of the three curves above or below the base line at any point, and comparing the sum of the distances found below the line with that of those found above it.

This property of the three-phase current has a very important result, namely, that only three wires are required for the three separate currents, since at any instant some one of the wires can act as a return conductor for the current

in the other two. This also allows the use of but three collector rings on the armature windings, one winding being connected either between each two rings or between one of the rings and a common junction. The former is represented in the diagram, Fig. 19, the latter in the diagram, Fig. 20. In each, R, R_1, and R_2 are the three collector rings, on which bear the brushes B, B_1, and B_2, and to which are connected the three armature windings *1*, *2*, and *3*. In Fig. 19, winding *1* is connected between rings R and R_2, winding *2* between rings R and R_1, and winding *3* between rings R_1 and R_2; while in Fig. 20, windings *1*, *2*, and *3* are respectively connected between rings R, R_1, and R_2, and a common junction *o*. The method of connection shown in Fig. 19 is known as the Δ (delta) or mesh connection. That shown in Fig. 20 is known as the **Y** or star connection.

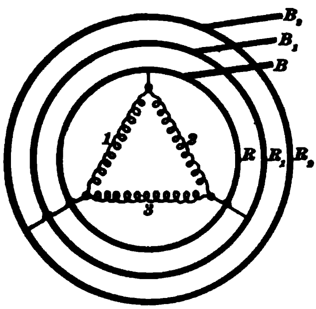


FIG. 19.

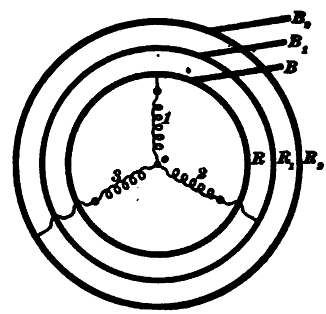


FIG. 20.

It should be understood that the above representations (Figs. 19 and 20) are merely *diagrammatic;* the separate windings are actually wound on the core in the same manner as illustrated in Fig. 12; the space between the two parts of each coil of each winding being made great enough to admit the coils of the other two windings, so that the surface of the core is entirely covered.

It will be seen that the method of connecting the windings shown in Fig. 20 is the same as is used in the Thomson-Houston constant-current open-coil dynamo (see Art. **20**), collector rings being here substituted for the commutator segments of that machine.

PROPERTIES OF THE ALTERNATING CURRENT.

36. It has been pointed out (Art. **70,** Part 2) that the heat generated in a conductor by a current, that is, the loss, is equal to $C^2 R$. As the strength of the current changes at every instant in an alternating-current circuit, it is evident that the heat generated also varies in the same manner; the temperature of the conductor does not correspondingly fluctuate, because the variations in the current are too rapid at the frequencies commonly used, but instead rises to some value where it remains steady. Now, if a certain direct current will cause the temperature of a conductor to rise to a certain point, it is evident that an alternating current may be sent through this same conductor, which, under the same conditions, will cause its temperature to rise to the same point, in which case the *effective* strength of the alternating current will be the same as the strength of the direct current.

In order that the alternating current may fulfil these conditions, the *mean* or *average* of the *square* of all its different values during a complete cycle must be equal to the square of the direct current with which it is compared; then the *square root* of this *mean square* will be its *effective strength*, which may be expressed in amperes.

As in a circuit which does not have any self-induction, the current is directly proportional to the E. M. F., it is further evident that the *effective* E. M. F. of an alternating current is also equal to the square root of the mean square of the various values of the E. M. F. which occur throughout the cycle.

When the form of the curve is about that shown in Figs. 17 and 18, as is usually the case, the effective current is equal to (very nearly) .707 of its maximum value, as is also the E. M. F. In speaking of an alternating current of so many amperes or volts, the *effective* current strength or voltage (.707 of the maximum) is meant, unless otherwise stated.

37. When the external circuit of an alternator is completed, the self-induction of that circuit prevents the current

from being proportional to the E. M. F. of the alternator; that is, when the E. M. F. is rising towards its maximum, the tendency of the current to increase is opposed by the self-induction of the circuit, and when the E. M. F. begins to decrease towards zero, the self-induction tends to keep up the current. In other words, the current *lags behind* the E. M. F.

If the circuit has little self-induction, this lag will be very slight; but if the self-induction is considerable, the lag is also considerable, and its effect must be considered.

If the current lags behind the E. M. F., C does not equal $\frac{E}{R}$, if E represents the applied E. M. F. as in the case of direct currents. This is due to the E. M. F. of self-induction, which opposes any change in the current due to a change in the applied E. M. F.; so that the *applied* E. M. F. which is sending the current through the circuit at any instant is equal to the *difference between* the *actual* E. M. F. used in overcoming resistance and the *counter* E. M. F. (that due to self-induction) at the same instant. The difference is here taken because the counter E. M. F. of self-induction is in itself negative, i. e., it tends to prevent the current from changing. If we considered the E. M. F. necessary to *overcome* self-induction (the equal and opposite of the E. M. F. of self-induction), then the *applied* E. M. F. would be equal at each instant to the *sum* of the E. M. F. necessary to send the current through the resistance and that necessary to *overcome* the self-induction. This will be understood from the curves in Fig. 21.

38. To find the applied E. M. F. necessary to send a given (alternating) current through a circuit having a certain resistance and a certain self-induction, it is necessary to find the E. M. F. due to the self-induction at various instants during each cycle. The E. M. F. required to overcome resistance being directly proportional to the current, the difference between it and the counter E. M. F. (of self-

induction) at any instant is the applied E. M. F. required. It is to be observed that if at any instant the signs of the two values are opposite, i. e., if one is + and the other – , the actual difference between them is the *sum* of their numerical values.

The E. M. F. of self-induction is, of course, proportional to the rate at which the lines of force generated cut the conductors of the circuit, that is, the *rate at which the number of lines of force generated changes.* This is in turn proportional to the *rate at which the strength of the current changes,* which is greatest when the actual value of the current is zero, for then it is changing from a certain strength in *one* direction to the same strength in the *opposite*, and is least (zero) when the strength of the current is at its maximum, for then the current is not changing at all.

39. If the instantaneous values of the current and the resulting E. M. F. of self-induction are graphically repre-

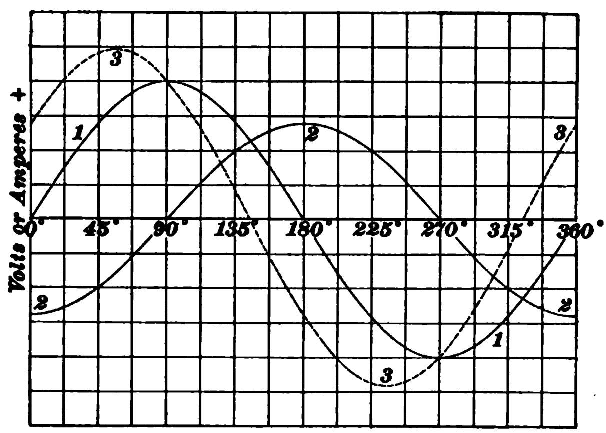


FIG. 21.

sented, the latter will be found to be a curve similar in shape to the current curve, and of the same frequency; but as its maximum value occurs at the instant the current curve is

zero, the *difference in phase* (see Art. **31**) between the two curves is 90°.

This is represented in Fig. 21, curve *1* being the current curve and curve *2* the curve of the E. M. F. of self-induction.

As the *actual* E. M. F. required to send the current through the resistance is of necessity proportional to that current, it is evident that by properly choosing the scale to which it is drawn, the current curve (curve *1*, Fig. 21) may also represent the curve of this *actual* E. M. F.

Considering this to be the case in Fig. 21, the *applied* E. M. F. curve may be constructed by taking the difference between the number of vertical divisions between curves *1* and *2* and the base line at various instants (or the *sum*, if one is + and the other −), and taking the result as the distance between the base line and the applied E. M. F. curve at those instants; in other words, applying the principle given in Art. **38.**

This applied E. M. F. curve, so constructed, is represented by curve *3*, Fig. 21.

It will be seen that in this curve for a part of the time the E. M. F. of self-induction acts in the *same* direction as the applied E. M. F., while at other times it acts in the opposite direction. The effect of this is, as stated in Art. **37,** that the current curve lags behind the E. M. F. curve, and the greater the self-induction the greater the lag.

The effect of this lag is to *increase the apparent resistance of the circuit;* for, as shown by Fig. 21, it takes a greater applied E. M. F. to force the current through the circuit than is represented by the drop (CR) due to that current; consequently, the energy expended in the circuit is *not* equal to the product of the E. M. F. and the current.

On this account, ordinary measurements of resistance, watts, etc., can not be relied upon if made with alternating currents, unless instruments especially designed for the purpose are used.

TRANSFORMERS.

40. The principal value of alternating currents is due to the fact that they can be *transformed;* that is, a current of 10 amperes at a pressure of 1,000 volts may be transformed to any higher or lower pressure, with a correspondingly less or greater current, and this transformed current will represent nearly as much energy as the original current. On this account, the energy necessary to operate, say a number of incandescent lamps, may be sent out from the dynamo at a high pressure and small current strength, so that only a small wire is needed to transmit the energy, effecting thereby a large saving in copper expense; then, at the point where the lamps are to be used, the current may be transformed from the high pressure used on the line, which would be dangerous to use inside a house, to a current of any convenient low pressure, which may then be used for operating the lamps.

This transformation is effected by setting up a mutual induction between a coil of wire connected to the source of the alternating current (the alternator), which coil is called the **primary,** and a second coil, called the **secondary,** which is connected to the circuit in which it is desired to utilize the electrical energy. See also Art. **6,** Part 2.

These two coils are wound upon a closed magnetic circuit of *laminated* iron, such as is used in armature cores. The lamination is intended to serve the same purpose here, namely, to prevent the generation of eddy currents which would otherwise be set up in the core, owing to the continual change of direction of the lines of force in the iron. This arrangement of primary and secondary coils, wound upon a magnetic circuit, is called a **transformer.**

41. The primary coil of a transformer has a great deal of self-induction, since a small current through it will cause a large number of lines of force to pass through the closed magnetic circuit, which lines cut the turns of the primary coil at a certain rate. Now, these lines also pass through the secondary coil, and cut its turns at the same rate, so that

if the number of turns in both primary and secondary is the same, the same E. M. F. will be set up in each; while if the number of turns differs, the E. M. F. set up in each will be in the *same ratio as the number of turns*. Thus, if the number of turns in the primary is 1,000 and in the secondary 100, the E. M. F. in the secondary will be $\frac{100}{1000} = \frac{1}{10}$ of that in the primary.

On account of its great self-induction, a high E. M. F. is required to send even a small current through the primary coil; in other words, the E. M. F. of self-induction is very nearly equal to the applied E. M. F., so that, generally speaking, the ratio between the applied E. M. F. of the primary and that generated in the secondary is the same as the ratio of the number of turns.

When the secondary circuit is closed, a current begins to flow in it. The effect of this current is to tend to send lines of force around the magnetic circuit of the transformer in the *opposite* direction to those which are due to the current in the primary coil; that is, to oppose the change in the lines of force which is producing the change in the current by changing the E. M. F.

This reduces the choking-back effect of the primary coil, and results in an increase in the primary current, which restores the number of lines of force to its original value. The result of these various reactions is that the E. M. F. generated in the secondary coil is (practically) constant, whatever the current in the secondary, within reasonable limits.

The current in the primary circuit is thus directly proportional to the current in the secondary *plus* a certain constant amount, which is necessary to send the lines of force through the magnetic circuit and to make up for the hysteresis and eddy-current losses in the iron due to the rapid reversals of the magnetism.

A transformer is similar in action to a dynamo and a motor connected together, and is subject to the same losses, except friction, which does not appear, since the material parts of the apparatus are stationary. The C^2R loss of

both primary and secondary and the hysteresis and eddy-current loss in the magnetic circuit are present, and may be calculated in a similar way as for a dynamo.

42. Fig. 22 represents one form of transformer, without the outside case. C is the *core*, or magnetic circuit.

The primary coil is divided into two parts, P and P_1, which are located on each side of the secondary coils S and S_1. The two parts of the primary coils are connected in series

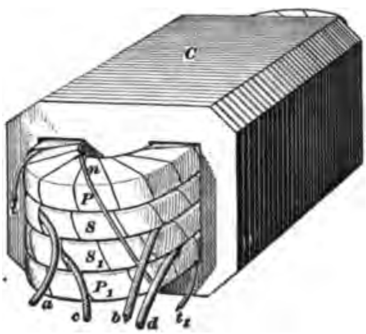


FIG. 22.

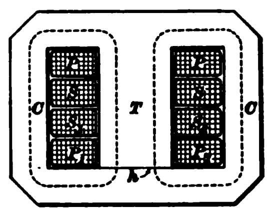


FIG. 23.

by the connection shown at n; t and t_1 are the primary terminals. The ends a and b of coil S and c and d of coil S_1 are brought out separately, in order that the two coils may be connected either in series or in parallel, as may be desired.

Fig. 23 represents a cross-section of this transformer, showing the method of construction. Here C represents one of the punchings of which the core is built up. In making the punching, it is cut across at h, leaving the tongue T, which is located between the coils $P\,P$, $S\,S$, $S_1\,S_1$, and $P_1\,P_1$. These coils are wound separately, and when completed are placed together and the punchings of the core slipped over them, the tongue T being bent out to one side until the punching is in place, when it is bent back again. The path of the lines of force through the magnetic circuit is indicated by the dotted lines. In some forms of transformers, the central piece T is made entirely separate;

a number of these pieces is assembled together and placed within the coils, the part *C* being slipped over. The magnetic circuit is then broken in two places, while in the case shown it is broken only at one place, *h*.

43. For ordinary work, transformers are wound for a primary E. M. F. of 1,000 or 2,000 (effective) volts, each secondary coil being wound to give about 50 volts. These may then be connected in parallel or in series, giving 50 or 100 volts as the secondary E. M. F. The efficiency of a 100-light transformer is about 96% at full load; in larger sizes the efficiency is higher, and in smaller sizes it is lower, as in dynamos.

44. It is often necessary to change direct current to alternating, and *vice versa*, and machines for accomplishing this are known as **rotary transformers.** The transformation might be effected by having an alternating-current motor coupled to a direct-current generator, simply using the alternating current to drive the generator. An arrangement of two machines is, however, not usually necessary, although such motor-generator sets are used to some extent. Rotary transformers are largely used for changing alternating current to direct for the operation of street railways, electrolytic plants, etc.

45. Suppose an ordinary Gramme ring armature to be revolved in a two-pole field, as shown in Fig. 24; a continuous E. M. F. will be generated and a continuous current obtained by attaching a circuit to the brushes *a*, *a'*. If, instead of the commutator, two collector rings were attached to opposite points of the winding, an alternating current would be obtained in a circuit connected to *b*, *b'*. If the machine be equipped with both commutator and collector rings, the armature may be revolved by means of direct current led in at the brushes *a*, *a'*, thus running it as a motor instead of it being driven by a belt. The conductors on the revolving armature will be cutting lines of force just as much as they were when the machine was driven by a belt;

therefore an alternating current will be obtained from the rings *b*, *b'*. In other words, the machine acts as a transformer, changing the direct current into a single-phase alternating current. If the operation be reversed and the machine be run as an alternating-current motor, the alternating current will be transformed into a direct one.

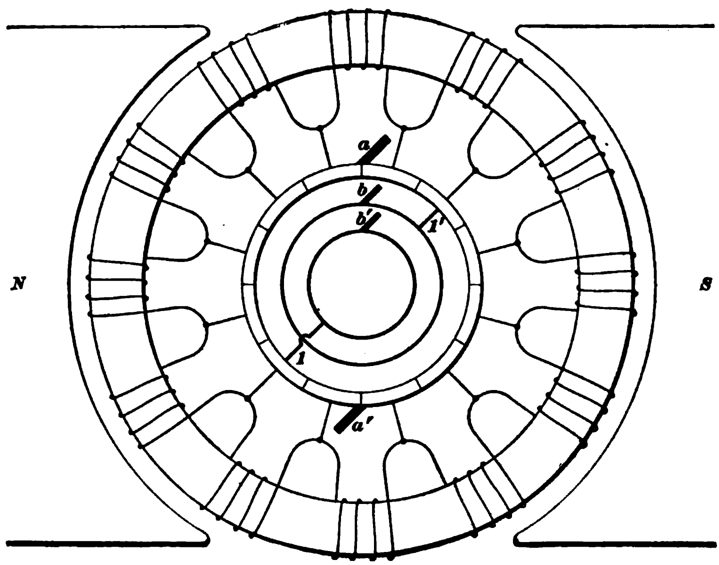


FIG. 24.

In the above single-phase rotary transformer, it is evident that the maximum value of the alternating E. M. F. occurs when the points *1*, *1'* to which the rings are connected are directly under the brushes *a*, *a'*; that is, the maximum value of the alternating E. M. F. is equal to the continuous E. M. F. For example, if the continuous E. M. F. were 100 volts, the *effective* volts on the alternating-current side would be 70.7, because the effective value is .707 times the maximum value. Therefore, if $\bar{E}$ is the alternating voltage and V the direct, we may write for a single-phase rotary transformer,

$$\bar{E} = .707\,V. \qquad \textbf{(1.)}$$

46. By connecting four equidistant points of a winding (similar to that described in Art. **45**), as in Fig. 17, to four collector rings, we would have a two-phase rotary transformer. The two phases would be related as shown in Fig. 17, and the E. M. F. of each phase would be determined in exactly the same way as in the case of a single-phase rotary transformer, such as described in Art. **45.**

47. By connecting three equidistant points of a winding, such as that described in connection with single-phase rotary transformers (Art. **45**), a three-phase transformer is obtained. Since all direct-current, constant-potential armatures have closed circuit windings, it follows that the connections on the alternating side of a three-phase rotary transformer are always Δ, the **Y** connection not being practicable. If $\overline{E}$ be the effective voltage between the lines on the alternating side of a three-phase rotary transformer and V the voltage of the continuous-current side,

$$\overline{E} = .612\,V. \qquad \textbf{(2.)}$$

48. In the rotary transformers, whose principles were just shown, the ratio of transformation is fixed, and the only way by which the transformed E. M. F. can be raised or lowered is to raise or lower the primary voltage, or the voltage of the current supplied to the machine. It would appear at first sight that a variation in field strength would cause a variation in the speed of a rotary transformer. This is true when *direct current* is supplied to the machine, the secondary voltage being alternating. However, when the primary voltage is *alternating*, the machine operates as an alternating-current motor, and a variation in field strength in no wise affects the speed at which the armature rotates. The reason for this will be seen when the subject of synchronous motors is taken up.

When the primary voltage is continuous, the speed would need to be varied in possibly only one case. That would be to synchronize the secondary alternating E. M. F. with a

corresponding alternating-current circuit with which the rotary transformer is to operate in multiple.

When the primary voltage is alternating, a variation in the secondary (continuous) E. M. F. is secured by varying the number of turns in the secondary of the transformer supplying the rotary transformer.

49. In order that the speed of rotary transformers may not be too high, it is usually necessary to make them with more than two poles. In fact, in general appearance, they are very similar to ordinary multipolar direct-current generators with the addition of the collector rings to one end of the armature. Fig. 25 shows one of these machines and

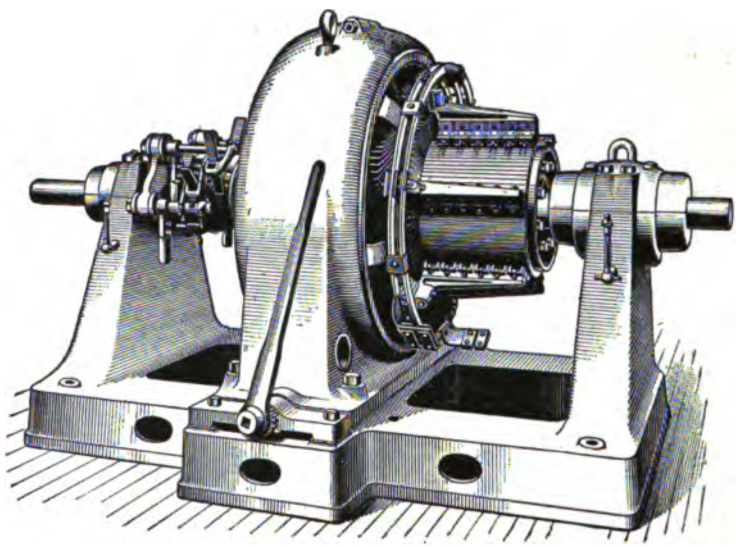


FIG. 25.

gives a very good idea as to the construction usually adopted. In this machine, the collector rings may be seen at the left-hand side of the machine. This particular machine is intended for electrolytic work calling for a large current output, and, for this reason, the commutator is larger than usual in order to obtain ample contact surface.

ELECTRIC MOTORS.

PRINCIPLES.

50. The principle upon which all electric motors operate is that given in Art. **25,** Part 2, namely, *that a conductor carrying a current will tend to move if placed in a magnetic field.* A motor then consists chiefly of a magnetic field and a conductor, or series of conductors, arranged to move in this field; that is, the requirements for a motor are the same as for a dynamo, and, as in a dynamo, the conductors are arranged around the surface of a drum or ring core, which rotates between the poles of an electromagnet.

Their difference can be summed up as follows: In the case of a dynamo, the mechanical energy delivered at the pulley rotates the armature in a magnetic field, and this results in the generation of an E. M. F. in the armature. In the case of a motor, an electric current is sent through the armature, and this results in a reaction between the armature conductors and the field, producing a rotation of the motor armature. The essential difference, therefore, between a dynamo and a motor is that in the case of the former, mechanical energy is transformed into electrical energy, while in the case of the latter, electrical energy is transformed into mechanical energy.

51. Motors may be divided into the same general classes as dynamos, according to the character of the current they require, as follows:

Constant-potential motors, which are supplied with a continuous current at a constant potential.

Constant-current motors, which are supplied with a continuous current of a constant strength.

Alternating-current motors, which are supplied with an alternating current.

CONSTANT-POTENTIAL MOTORS.

52. If the fields of a constant-potential dynamo are excited, and a current is supplied to the armature from some source, as represented at D in Fig. 26, so that the current enters at the brush $+B$, and passing through the winding in the direction indicated by the arrow-heads, leaves at

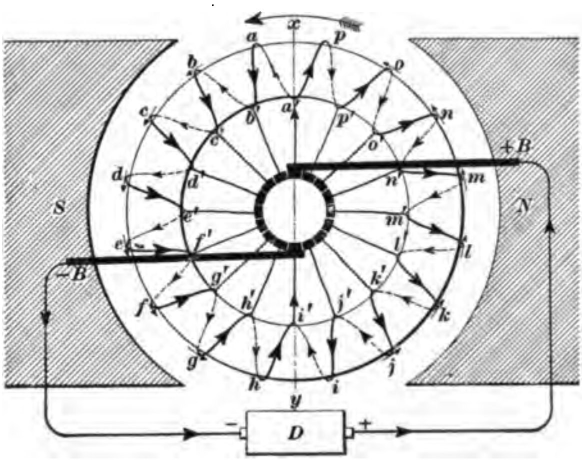


FIG. 26.

brush $-B$, it will be found by applying the thumb-and-finger rule given in Art. **26,** Part 2, that all the conductors under the S pole face, b, c, d, e, f, and g, will tend to move *downwards*, and all those under the N pole face, j, k, l, m, n, and o, will tend to move *upwards*, as indicated by the small arrows.

These forces combine to produce a tendency of the armature to rotate about its axis, as indicated by the large arrows, which tendency is called the **torque** of the motor.

The amount of this torque—which is usually expressed in **pound-feet,** that is, a certain number of pounds acting at a radius of a certain number (usually 1) of feet—depends upon (1) the strength of the field, (2) the number of conductors, (3) their mean distance from the axis of the

armature, and (4) the amperes in each conductor. In any given machine, the second and third conditions are constant, so that the torque depends upon the strength of the field and of the current.

53. If the armature is stationary, the E. M. F. required to send the current through the winding is only that necessary to overcome the drop, which is due to the resistance of the winding. If the torque exerted by this current is greater than the opposition to motion, so that it causes the armature to revolve, the motion of the conductors through the field generates in them an E. M. F. which is *opposed to the E. M. F. that is sending the current through the armature*, as will be seen by applying the thumb-and-finger rule given in Art. **8**, Part 2, to Fig. 26.

This opposing E. M. F., or **counter E. M. F.**, as it is called, then diminishes the effect of the applied E. M. F., so that the current is reduced, reducing the torque. Should the torque still be greater than the opposition to motion, the speed of the armature will continue to increase, increasing the counter E. M. F., and thereby further reducing the current and the corresponding torque, *until the torque just balances the opposition to the motion*, when the speed will remain constant.

54. At all times the drop of potential through the armature is equal to the *difference between the counter and the applied E. M. F.'s*, and as the product of this drop and the current represents energy wasted, it is desirable to make it as low as possible. In good motors of about 10-horsepower output, the drop in the armature is seldom more than about 5% of the applied E. M. F., and is less in larger machines.

This being the case, it is evident that if the armature is at rest, so that it has no counter E. M. F., and is connected directly to the mains, a very large current will flow through it, which would be liable to damage the armature. On this account an external resistance, called a **starting**

resistance, is connected in series with the armature when it is to be started. This resistance is made great enough to prevent more than about the normal current from flowing through the armature when it is at rest; as the armature speeds up and develops some counter E. M. F., this resistance is gradually cut out, until the armature is connected directly to the mains, and is running at its normal speed.

The energy represented by the product of the drop in the armature and the current is wasted; that represented by the product of the current and the rest of the E. M. F., that is, the counter E. M. F., is the energy required to keep the armature in motion. This energy is expended in overcoming the friction losses and core losses in the motor itself, which are of the same nature and effect as the similar dynamo losses (see Arts. **64** and **65,** Part 2), and also in overcoming the resistance to motion of whatever external apparatus is driven by the motor.

Aside from the comparatively small amount of current required to furnish the torque necessary for overcoming the losses in the motor itself, which is practically constant, the amount of current taken from the mains is directly proportional to, and varies automatically with, the amount of the external load, for if this external load is increased, the current which has been flowing in the armature can not furnish sufficient torque for this increased load, so that the machine slows down. This decreases the counter E. M. F., which immediately allows more current to flow through the armature, increasing the torque to the proper amount. If the external load is decreased, the current flowing furnishes an excess of torque, which causes the speed to increase, increasing the counter E. M. F. and decreasing the current until it again furnishes only the required amount of torque.

Since the counter E. M. F. is very nearly equal to the applied, it is only necessary for it to vary a small amount to vary the current within wide limits. For example, if the resistance of a certain armature is 1 ohm, and it is supplied

with current at a constant potential of 250 volts, then, when a current of 10 amperes is flowing through it, the drop is $10 \times 1 = 10$ volts, and the counter E. M. F. is $250 - 10 = 240$ volts. Now, if the current is reduced to 1 ampere, the drop is $1 \times 1 = 1$ volt, and the counter E. M. F. is $250 - 1 = 249$ volts; that is, the counter E. M. F. only varies $\frac{9}{240}$, or 3.75%, while the current varies $\frac{9}{10}$, or 90%.

55. The field-magnets of constant-potential motors may be either shunt wound or series wound.

If shunt wound, and supplied from a constant-potential circuit, the magnetizing force of the field coils is constant, giving a practically constant field. This being the case, the counter E. M. F. is directly proportional to the speed, so that variations of the load make only slight variation in the speed. A shunt-wound motor is then (practically) a *constant-speed* motor.

With series-wound motors, the strength of the field varies with the current. If the load on such a motor is reduced, the excess of torque makes the armature speed up, but as the resulting decrease of the current decreases the field strength, the armature must speed up to a much greater extent, in order to increase the counter E. M. F. to the right degree, than would be necessary if the field were constant. If the load is increased, the increase in the current so increases the field strength that the speed must decrease considerably, in order to decrease the counter E. M. F. by the right amount. The speed of a series-wound motor, then, varies largely with variations in the load.

An advantage of the series motor is that if a torque greater than the normal is required, it can be obtained with less current than with a shunt motor, since the increased current increases the field strength, and the torque is proportional to both these factors (Art. **52**).

56. It would not be practicable to make the field strength of a shunt motor as great as is possible to get with

a series motor, since it would require a very large magnetizing force (Art. **35,** Part 2), and with the shunt winding, this extra magnetizing force would have to be expended all the time, whether the strong field was required or not, which would be very wasteful. In the series motor, however, this extra magnetizing force is expended only while it is needed.

A disadvantage of the series winding is that if all the load is taken off, the current required to drive the motor is very small, making a weak field, which requires such a high speed to generate the proper counter E. M. F. that the armature is liable to be damaged. In other words, the motor will *race* or *run away*, if the load is all removed. This can not occur with the shunt motor as long as the field circuit remains unbroken.

On account of the above features, shunt motors are used to drive machinery that requires a nearly constant speed with varying loads, or which would be damaged if the speed should become excessive, such as ordinary machinery in shops and factories, pumps, etc. Series motors are used on street-cars, to operate hoists, etc., where, on account of the gearing used, the load can not be entirely thrown off, and the torque required at starting and getting quickly up to speed is much greater than the normal amount.

REGULATION.

57. The *torque* of a motor is a matter of current only; that is, for a given current, the torque will be the same whatever may be the speed, under otherwise the same conditions. The *speed* at which the armature runs is a matter of E. M. F. only; that is, with a given current the speed will be proportional to the applied E. M. F., or, more strictly, the counter E. M. F., other conditions remaining the same.

It has been shown that the torque will automatically regulate itself for changes in the load. The speed, however,

may be varied by varying the applied E. M. F., or the strength of the field. A change in speed may or may not result in a change in the torque required, depending on the character of the work done by the motor.

The simplest way to vary the applied E. M. F. is to insert a resistance, in series with the armature, similar to the starting resistance. By varying this resistance, the applied E. M. F. at the terminals of the motor is also varied, although the E. M. F. of the mains remains constant. It is evident that the energy represented by the drop through the resistance is converted into heat, and is thereby wasted; therefore, for great variations in speed this method is not economical, though often very convenient.

The applied E. M. F. may also be varied by varying the E. M. F. of the generator supplying the current; but this can only be done where a single generator is supplying a single motor or several motors, whose speed must all be varied at the same time; so that this method is used only in special cases.

If the strength of the field is changed, the speed necessary to give a certain counter E. M. F. will also be changed, and this gives a convenient method of varying the speed. If the strength of the field is lessened, the speed will increase, and if the field is strengthened, the speed will decrease. With shunt motors, the field may be weakened by inserting a suitable resistance in the field circuit, as in shunt dynamos; with series motors, the same result may be obtained by cutting out some of the turns of the field coils or by placing a suitable resistance in parallel with the field coils, as in series dynamos.

This method of regulation is also of limited range, since it is not economical to maintain the strength of the field much above or below a certain density. The resistance method described above being rather more simple, it is generally used. For special cases, such as street-railroad work, various special combinations of the above methods of regulation are used, which need not be described here.

CONNECTIONS.

58. Fig. 27 shows the manner in which a shunt motor is connected to the terminals + and −. of the circuit. It will be seen that the current through the shunt field does not pass through the resistance *R* which is connected in the armature circuit. This is necessary, since to keep the field strength constant the full difference of potential must be maintained between the terminals of the field coil, which would not be the case if the rheostat were included in the field circuit, for then the difference of potential would be only that existing between the brushes $+B$ and $-B$. As on starting the motor this difference of potential is small, only a small current would flow through the field coils, which would generate such a weak field that an excessive current would be required to furnish the necessary torque for starting the motor.

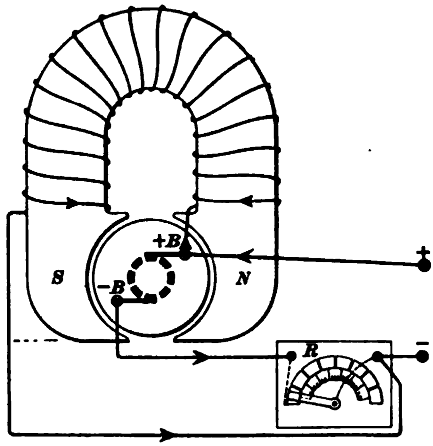


FIG. 27.

When connected as shown, however, the field is brought up to its full strength before any current passes through the armature, so this difficulty does not arise.

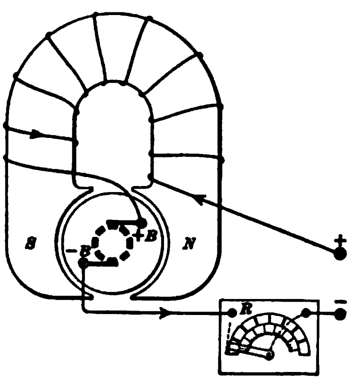


FIG. 28.

59. Since in a series motor the same current flows through both armature and field coils, the starting resistance may be placed in any

part of the circuit. The diagram in Fig. 28 illustrates one method of connecting a series motor to the line terminals + and —. Here the starting or regulating resistance R is placed between the — line terminal and the brush — B of the motor.

To reverse the direction of rotation of a motor, it is necessary to reverse *either* the polarity of the field or the direction of the current through the armature. (See Art. **26**, Part 2.) It is usual to reverse the direction of the current in the armature, a switch being used to make the necessary changes in the connections.

Fig. 29 shows the connections of one form of reversing-switch. Two metal bars B and B_1 are pivoted at the points T and T_1; one is extended and supplied with a handle H, and the two bars are joined together by a link L of some insulating material, such as fiber. Three contact pieces a, b, and c are arranged on the base of the switch, so that the free ends of the bars B and B_1 may rest either on a and b, as shown by the full lines, or on b and c, as shown by the dotted lines. The line is connected to the terminals T and T_1, and the motor armature between a and b, or *vice versa*, a and c being connected together.

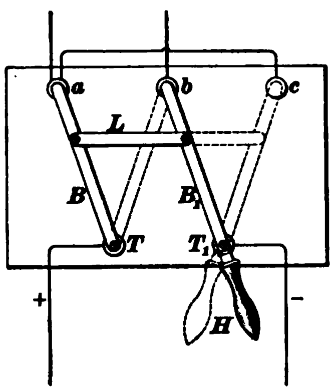


FIG. 29.

When the switch is in the position shown by the full lines, T is connected to a by the bar B, and T_1 to b by the bar B_1. If the switch is thrown by means of the handle H into the position indicated by the dotted lines, T is connected to b by the bar B, and T_1 to a by the bar B_1 and the connection between c and a. The direction of the current through the motor armature, or whatever circuit is connected between a and b, is thus reversed.

In order to reverse only the current in the armature, the reversing-switch must be placed in the armature circuit

only. Fig. 30 represents the connection for a reversing-shunt motor (*a*) and a reversing-series motor (*b*); + and − are the line terminals; R, the starting resistance; B and B_1

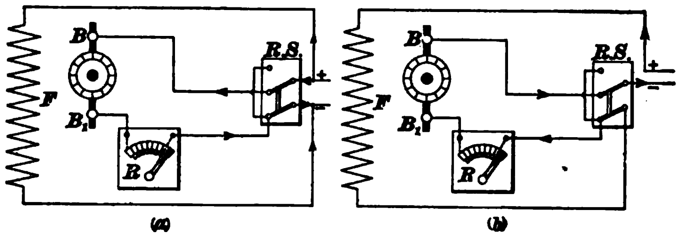


FIG. 30.

the brushes of the motor; and F, the field coil of the motor. Some manufacturers combine the starting resistance and reversing-switch in one piece of apparatus.

60. In connecting up motors, some form of main switch is used to entirely disconnect the motor from the line when it is not in use.

To prevent an excessive current from flowing through the motor circuit from any cause, short strips of an easily melted metal, known as **fuses,** mounted on suitable bases, known as **fuse boxes** or **cut-outs,** are placed in the circuit. These fuses are made of such a sectional area that a current greater than the normal heats them to such an extent that they melt, thereby breaking the circuit and preventing damage to the motor from an excessive current. The length of fuse should be proportioned to the voltage of the circuit, a high voltage requiring longer fuses than a low voltage, in order to prevent an arc being maintained across the terminals when the fuse melts.

If desired, measuring instruments (ammeter and voltmeter) may be connected in the motor circuit, so that the condition of the load on the motor may be observed while it is in operation. All these appliances, regulating resistance, reversing-switch, fuses, instruments, etc., are placed *inside* the main switch; that is, the current must pass through the main switch before coming to any of these appliances, so

that opening the main switch entirely disconnects them from the circuit, when they may be handled without fear of shocks.

61. To illustrate the manner in which these various apparatus are connected, the following example in connecting a series-wound motor is given:

EXAMPLE IN CONNECTING.—Draw a diagram showing the connections of a series-wound motor with reversing-switch, regulating resistance, ammeter, fuse boxes, main double-pole switch, and voltmeter, indicating the potential of the line inside the main switch.

Fig. 31 shows the connections that should be made. The terminals of the circuit supplying the current are connected to the upper contacts of the main switch *M. S.*, and the terminals of the motor circuit are connected to the lower contacts. A fuse box *F. B.* is placed in each side of the

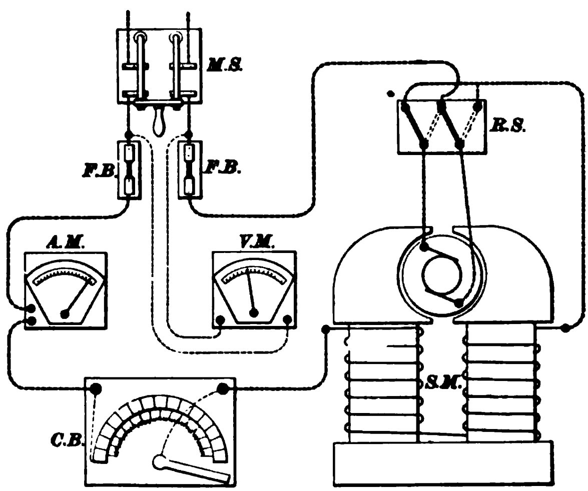


FIG. 31.

motor circuit, just inside the main switch. The voltmeter *V. M.* is connected to each side of the circuit just above the fuses, so if a fuse is blown, the voltmeter will still indicate the difference of potential between the mains if the circuit is "alive."

The armature terminals of the motor *S. M.* are connected to one side of the reversing-switch *R. S.*, the other terminals being connected to the fuse boxes, one directly, the other through the field coils of the motor, starting and regulating resistance *C. B.*, and ammeter *A. M.*

OUTPUT.

62. The *torque* of a motor corresponds to a certain number of *pounds pull* exerted at the circumference of the pulley, or at the pitch-circle of the gear, or, in general, at some radial distance from the center of the shaft. As stated, this torque is the same for a given current whatever the speed. But for each revolution of the motor, the point at which the pull (torque) is exerted moves through a certain distance, equal to $3.1416 \times$ the diameter of the circle, or to $2 \times 3.1416 \times$ the *radius* of the circle at the circumference of which the torque is considered to act. Each revolution of the motor, then, when a certain torque is exerted, corresponds to a certain number of *foot-pounds of work done.*

This number of foot-pounds will be the same for a given torque, whatever the radius of the circle through which its point of application moves, for, if a radius be taken that is twice as long as another, the distance moved through will be twice as great, but the pull in pounds will be only half as much, so that their product remains the same. For the sake of uniformity, a standard radius of one foot is used, and the torque is expressed in *pounds at one foot radius.* See also Art. **52.**

It will be noticed that the words *moment* and *torque* have nearly the same meaning. If the distance from the center to the line of action of the force whose moment it is desired to express was always measured in feet, then the words moment and torque would have the same meaning.

The foot-pounds of work done in each revolution and the number of revolutions per minute being known, the foot-pounds of work done per minute, and from that the horse-power, may be found by the following formula:

If T represents the torque in pounds at one foot radius, and S the number of revolutions per minute, then the horsepower

$$\text{H. P.} = \frac{2 \times 3.1416\, TS}{33,000} = .0001904\, TS. \qquad \textbf{(3.)}$$

That is, *to obtain the horsepower of a motor, multiply 3.1416 by 2, this product by the torque expressed in pounds at one foot radius, and this product by the number of revolutions per minute; divide the final product by 33,000.* An alternative method is to use the constant .0001904, and multiply this by the product of the torque and speed expressed as above.

If the H. P. and the torque are known, the number of revolutions per minute may be found from a modification of the above formula:

$$S = \frac{33,000 \text{ H. P.}}{2 \times 3.1416\, T} = \frac{\text{H. P.}}{.0001904\, T}. \qquad \textbf{(4.)}$$

Or, if the H. P. and the number of revolutions per minute are known, the torque may be found from the formula

$$T = \frac{33,000 \text{ H. P.}}{2 \times 3.1416\, S} = \frac{\text{H. P.}}{.0001904\, S}. \qquad \textbf{(5.)}$$

63. Fig. 32 illustrates a method of measuring the torque of a motor by means of a **Prony brake.**

This brake consists of two blocks of wood B, B, made to fit the surface of the pulley P. These two blocks bear upon the pulley on opposite sides, as represented, and their pressure on the pulley is regulated by means of the thumb-nuts N, N on the bolts which hold the two parts of the brake together.

The lower of the two blocks of wood is extended in both directions, forming on the one side an arm A, which presses on the platform of a set of scales S, and on the other a place where weights W may be placed to balance the weight of the arm A. A spike, or lag-bolt, C should be driven through the end of the arm A to better locate the point where it presses on the scale platform.

If the pulley P is revolved in the direction indicated by the arrow, the friction of the brake will cause it to tend to rotate with the pulley, which will cause the spike in the end of the arm A to press down on the scale platform, and the amount of this pressure may be weighed by the scale-beam. The *product* of the number of pounds pressure and the *horizontal* distance R between the point C and the center of the pulley in feet, will give the torque in *pound-feet*.

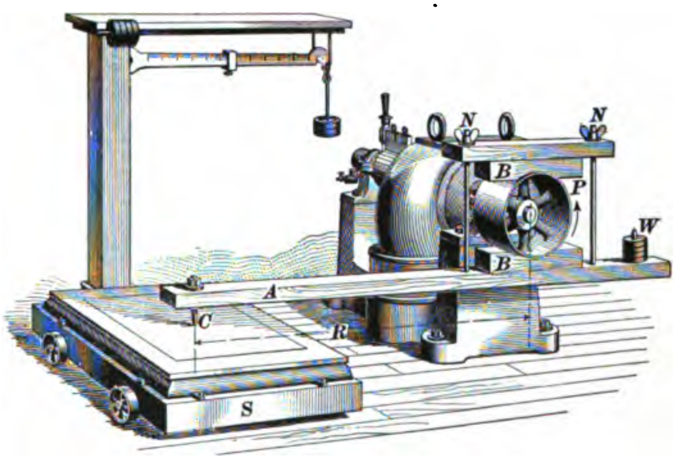


FIG. 32.

Then, if the number of revolutions per minute of the motor is counted, the horsepower absorbed by the friction of the brake, that is, the output of the motor, may be calculated by formula **3.** If at the same time the amperes input and the voltage at the motor terminals are measured, their product will be the watts input, and by reducing the output and the input to the same units, the efficiency may be calculated by dividing the output by the input. (See formula **2,** Part 2.)

64. The following example shows the application of the above rules and method of testing motors:

EXAMPLE.—A given shunt-wound motor is designed for an output of 10 H. P. and to be run on a constant-potential circuit of 230 volts.

When driving a certain piece of machinery, it requires an input (to both field and armature) of 35 amperes at 230 volts. It is desired to find the actual horsepower required to drive this machinery. The motor is disconnected from its load and a Prony brake rigged up as shown in Fig. 32. The thumb-nuts are screwed up until an ammeter in the motor circuit indicates that 35 amperes are flowing through the motor circuit, and the voltage at the terminals is found to be 230 volts. Under these conditions, the pressure on the scale platform is found to be 24 pounds, and the speed of the motor 800 revolutions per minute. The horizontal distance between the center of the shaft and the point where the brake arm rests on the scales is 30 inches. What is the output of the motor at this load in horsepower, and what is its efficiency?

SOLUTION.—The distance R (Fig. 32) being 30 in., or $2\frac{1}{2}$ ft., and the pressure on the scales being 24 lb., the torque of the motor is $24 \times 2\frac{1}{2} =$ 60 pound-feet. Substituting this value for T, and 800 for S, in formula **3**, gives $\text{H. P.} = \frac{2 \times 3.1416 \times 60 \times 800}{33,000} = \frac{301,593.6}{33,000}$.

NOTE.—As the instruments used are liable to slight errors, four figures (other than the zeros) left in the calculations will be near enough: if the last figure dropped is equal to 5 or more, the last figure *kept* should be increased 1.

Then, $\frac{301,600}{33,000} = 9.1393$, or 9.139 H. P. is the output of the motor. Ans.

The input is $35 \times 230 = 8,050$ watts. Reducing 9.139 H. P. to watts gives $9.139 \times 746 = 6,817.694$, or 6,818 watts.

Then, by formula **2**, Part 2, the efficiency $\mathbf{E} = \frac{6,818 \times 100}{8,050} =$ 84.7 per cent. Ans.

65. The loss represented by the difference between the input and the output is made up of exactly the same elements as the total loss in dynamos; that is, mechanical friction, core loss, field loss, and armature loss. As in dynamos, the armature loss and field loss may be calculated from the resistance of the armature and field coils, remembering that in a shunt motor the *armature* current is *less* than the *total* current, since the field circuit is in parallel with the armature. The core loss and friction taken together evidently equal the difference between the total loss and the sum of the armature and field losses; they can not be separated without making special tests.

In a shunt motor, the field loss, core loss, and friction are all practically constant at all loads, since the speed is nearly constant. This being the case, the *watts required to run the motor without any external load whatever* is a measure of these losses plus a certain small amount of armature C^2R, which may be calculated, though it is usually small enough to be neglected without much error. This being the case, the output which a motor will give at any given input will be very closely equal to that input less the watts required to run the motor free, and also less the armature C^2R loss at the given input; from this the efficiency may also be calculated. To determine the efficiency of the motor at any load within its rated capacity, then, it is only necessary to carefully measure its input at no load (running *light* or *free*), and to make the above calculation. This, however, will give no idea of its performance as to heating and sparking, under the calculated load, so that the Prony-brake test is more satisfactory.

For example, a certain shunt-wound motor requires a current of 1.2 amperes at 500 volts when running *free*, i. e., without external load. Its armature resistance is 2.4 ohms and its field resistance is 834 ohms. Its field current is then $\frac{500}{834} = .5995$ ampere, or say .6 ampere. Its armature current is then $1.2 - .6 = .6$ ampere, and its armature loss only $.6 \times .6 \times 2.4 = .864$ watt, which may be neglected.

The input amounts to $1.2 \times 500 = 600$ watts, of which the field loss is $.6 \times 500 = 300$ watts.

If the efficiency when taking 10 amperes at 500 volts is wanted, it may be found from the above figures, as follows: Total input, $10 \times 500 = 5{,}000$ watts. Field loss and core loss and friction combined amount to 600 watts, as found above. The armature loss amounts to $9.4 \times 9.4 \times 2.4 = 212.064$, or say 212 watts. The total loss is then $600 + 212 = 812$ watts, so that the output is $5{,}000 - 812 = 4{,}188$ watts, and by formula **2**, Part 2, the efficiency $\mathbf{E} = \frac{4188}{5000} = .837$, or 83.7%. In a similar manner the efficiency at any other input, or the input required for any given output, may be found.

The input, consequently the output, of constant-potential motors is limited by the same factors that limit the output of dynamos, namely, heating and sparking.

In motors, as the direction of the current, for the same direction of the lines of force of the field and of rotation, is *opposite* to that in a dynamo, the armature reaction shifts the neutral space in the opposite direction, that is, *backwards*, *against* the direction of rotation. (Compare Fig. 26 with Fig. 28, Part 2. See also Art. **29**, Part 2.) Consequently the brushes of a motor must be shifted *backwards* as the load increases.

THE CONSTRUCTION OF CONSTANT-POTENTIAL MOTORS.

66. It should be clear that any direct-current constant-potential machine can be used either as a motor or a dynamo: If supplied with current, it turns and furnishes mechanical power; if supplied with mechanical power, it turns and furnishes an E. M. F. which can be used to supply a current. Consequently, the statements already made concerning the construction of dynamos apply equally well to the construction of motors, and the same varying types of field-magnets, bipolar and multipolar, are used with either drum-wound or ring-wound armatures. (See Figs. 45 and 49, Part 2.)

For certain special applications of motors, such as for street-cars, locomotives, and the like, certain features must be introduced in the design to meet the peculiar conditions under which the motor is to operate; these features need not be discussed here.

EXAMPLES FOR PRACTICE.

1. A certain shunt-wound motor gives an output of 28 H. P. and requires an input of 96.6 amperes at 240 volts. Its armature resistance is .096 ohm and its field resistance 150 ohms. Find the per cent. of the above input lost in the core and in friction combined. Ans. 4.51%.

2. What is the counter E. M. F. generated in the above motor, when running under the conditions given? Ans. 230.88 volts.

3. A series-wound motor has an armature resistance of .5 ohm and a field resistance of .35 ohm. When tested with a Prony brake, it gave a torque of 62 foot-pounds when running at a speed of 950 revolutions per minute, and took 44 amperes at 240 volts. Find (*a*) the efficiency of the motor; (*b*) the armature loss in per cent. of the input; (*c*) the field loss in per cent. of the input; and (*d*) the core loss and friction combined in per cent. of the input.

Ans. (*a*) 79.22%. (*b*) 9.167%. (*c*) 6.42%. (*d*) 5.193%.

4. After the test made in Art. **64** is completed, the tension on the brake thumb-nuts is slackened until the motor takes 24 amperes, the E. M. F. remaining at 230 volts. The pressure on the scale platform is found to be 15.66 lb. The armature resistance is then measured and found to be .4 ohm, and the field resistance 230 ohms. Using only four figures in any of the calculations, etc., calculate (*a*) the speed (assuming it to be proportional to the counter E. M. F., and taking it to the nearest whole revolution only); (*b*) the horsepower output; (*c*) the input in watts; (*d*) the efficiency; (*e*) the per cent. of the input lost in the fields; (*f*) the per cent. of the input lost in the armature; and (*g*) the per cent. of the input lost in the core and in friction combined.

Ans. (*a*) 816 R. P. M. (*b*) 6.083 H. P. (*c*) 5,520 watts. (*d*) 82.156%. (*e*) 4.167%. (*f*) 3.833%. (*g*) 9.844%.

CONSTANT-CURRENT MOTORS.

67. If a series motor be supplied with a constant current, the resulting torque will also be constant. This being the case, if this torque is in excess of that required to overcome the opposition to the motion of the armature, the speed of the motor will increase indefinitely; that is, the motor will run away, until the armature bursts from centrifugal force. The increase in the counter E. M. F. of the machine merely increases the applied E. M. F. in the same proportion, this being automatically regulated by the dynamo.

Motors intended for constant-current circuits must then be provided with some sort of regulator for varying the torque according to the load.

The usual method of regulation is to attach to the motor shaft a device like a centrifugal governor. If the speed of the motor exceeds a certain limit, by reason of the load being thrown off, the weights of the governor move outwards, and this motion is made to decrease the torque of the motor, either by cutting out some of the turns of the field coils or by shifting the brushes around the commutator. The first method reduces the torque by weakening the field; the second causes the torque of a part of the armature winding to oppose that of the rest, so that the resulting torque is diminished.

Constant-current motors are made only in the smaller sizes, and are little used, being generally less satisfactory in their operation than constant-potential machines; they need no further description here.

ALTERNATING-CURRENT MOTORS.

SYNCHRONOUS MOTORS.

68. Single-Phase Synchronous Motors.—If an alternating-current generator has its fields excited from some source of direct current, and a simple, single-phase, alternating current is supplied to the armature, the rapid reversal of the current will produce a torque that as rapidly reverses its direction; consequently, the armature will remain at rest, since the tendency to turn in any one direction is reversed before the armature has time to start.

If, however, the armature is rotated from some external source until its own E. M. F. is not only of the *same frequency*, but opposite *in phase* to the E. M. F. of the source of the alternating current, and is then connected to the alternating-current circuit, the torque will be continuous in one direction, and the armature will continue to rotate, because each time the current reverses its direction in the armature conductors they will have moved into a field of the *opposite* polarity, so that the *reversed* current will give a torque in the *same* direction.

It is necessary that the two E. M. F.'s (that of the circuit and that of the motor armature, i. e., the *counter* E. M. F.) should be in phase, for if that is not the case, the maximum E. M. F. of the circuit will occur at the instant that there is little or no counter E. M. F. to oppose it, so that an excessive current will flow through the armature, which will not produce a corresponding torque, since the reaction of this excessive current will very much weaken the magnetic field of the machine.

In order that the frequency of the counter E. M. F. should be the same as that of the applied E. M. F., it is evident that the motor must be driven at such a speed that the product of the number of revolutions per second and the number of *pairs* of poles of its field-magnets shall equal the frequency desired. (See Art. **27.**)

69. When the counter E. M. F. of the motor is exactly opposite in phase to the applied E. M. F., it is evident that a coil of the motor armature must be in exactly the same position relative to the fields through which it is moving as a coil of the generator is to its fields. On this account these motors are called **synchronous** motors, synchronous meaning "occurring at the same time."

If these two E. M. F.'s are made exactly equal, then no current can flow through the motor armature when they are connected together; but just as soon as the motor armature *slips back* a sufficient fraction of a revolution for its coils to be in a certain position (relative to the fields) *an instant later* than the generator coils, then a current can flow through the motor armature and exert a torque to drive it.

If this torque is sufficient to drive the armature, it does not slip back further; if not sufficient, it slips back a little more until the increased current does furnish torque enough. If the load changes, the armature slips back a little or moves ahead a little, according to whether the load increases or decreases.

The total amount of this slip of the armature at the maximum load does not exceed about a quarter of the width of a

pole-piece, or in a ten-pole machine, about $\frac{1}{80}$ revolution, so that the *revolutions per minute* do not change with changes in the load, if the frequency is kept constant. If the load increases beyond the capacity of the machine, so that more than this amount of slip takes place, the excessive current which flows distorts and weakens the field to such an extent that little or no torque is exerted, and the armature stops.

The action of a synchronous motor may be likened to a pulley (the generator) driving another (the motor) by means of a spring, as represented in Fig. 33, where G represents the driving pulley, M the driven, and S is the spring fixed firmly to the driving pulley and playing between two pins on the driven pulley. If there is no load on the driven pulley, the spring will be nearly straight, as represented by the full lines; but if a load is thrown on the driven pulley, the additional torque required will bend the spring, as represented by the dotted lines, so that the driven pulley *slips back* a little, with reference to the driving pulley, although the number of revolutions per minute of each remains the same.

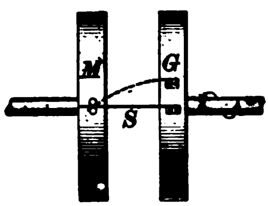


FIG. 33.

If the torque becomes excessive so that the spring is bent beyond its elastic limit, it breaks, and the driven pulley stops.

When supplied from a circuit of a constant frequency, there is then only one speed at which the motor can run, and there is no method of regulating the speed, except by varying the frequency of the applied E. M. F., which is not practicable. If the field is weakened, more current is required to give the same torque, but the speed remains the same; if the applied E. M. F. is decreased (without changing the frequency), the armature must *slip back* a little more to allow the same current to pass through the armature, but the speed remains the same.

70. If a single-phase generator is used as a motor, it will not be self-starting. Single-phase synchronous motors are manufactured by the Fort Wayne Electric Works, which are self-starting, with or without load. One of these machines is illustrated in Fig. 34, and a brief description will serve to explain the principle employed in starting.

The general appearance of the machine can be seen from Fig. 34, which is quite similar in appearance to a multipolar direct-current machine.

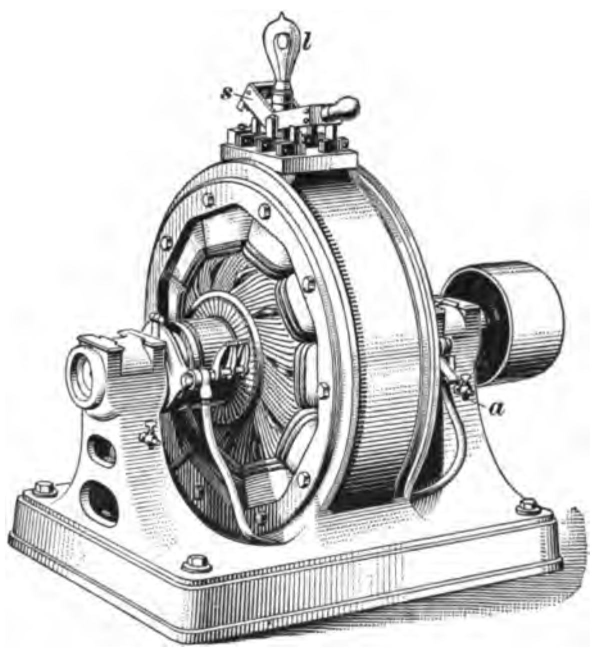


FIG. 34.

The laminated field in the machine illustrated has ten poles. These are provided with two windings. One of these is composed of a few turns per pole of comparatively heavy wire, and another of a large number of turns of light wire. The former is used in starting and the latter serves to supply the field excitation after the machine has been brought to speed.

The armature is provided with two windings, one an ordinary distributed winding connected to the commutator shown at the left end of the machine, and the other a shuttle winding, concentrating a number of distinct and regularly alternating poles around the armature. The two ends of this latter winding are connected to two collector rings at the pulley end of the machine. Bearing on these rings are two brushes, one of which can be seen at *a*.

The operation of the machine can be summed up as follows: In starting, the heavy field winding and distributed armature winding are connected in series. These connections to the circuit are made by means of the special knife switch mounted on top of the machine. Its starting position is that shown in the figure. The alternating current reverses its direction in the armature and field simultaneously, producing a torque in one direction. This brings the machine rapidly up to synchronous speed, which is indicated by the illumination of a lamp *l* connected to the shuttle winding on the armature. When this speed has been reached, the handle of the switch is lifted and the shuttle armature winding thereby directly connected to the alternating supply circuit. The field requiring direct current receives its excitation from the fine wire winding, which is, by means of the switch, connected to the distributed armature winding through the brushes and commutator shown at the left end of the machine.

71. Polyphase Synchronous Motors.—Synchronous motors for polyphase circuits are similar in construction to polyphase generators. With regard to their construction, these machines can be divided into two general classes: (1) those with internally revolving fields; (2) those with internally revolving armatures.

Machines of the first class are those used for such purposes as driving arc-light dynamos, frequency changes, etc. The external stationary member is made of laminated soft-iron disks, with inwardly projecting radial teeth. The

winding is similar to that of the stationary member of a polyphase induction motor, as will soon be described. The effect of the polyphase currents (either two or three phase) is to cause a rotating magnetic field.

In starting, a current is induced in the internal field, which has radial poles. When the machine is working at synchronous speed, the internal field is energized by a continuous current, and the motor is now capable of furnishing power. Fig. 35 shows a three-phase machine with stationary armature and internally revolving field. The field is supplied with its exciting current by the two collector rings shown. Such a machine could be operated either as a three-phase generator or a three-phase synchronous motor.

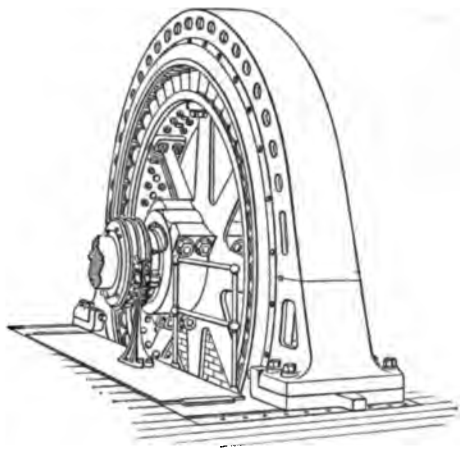


FIG. 35.

Machines belonging to the second class, as divided above, are used principally as rotary converters. Here the winding on the armature causes a rotating magnetic field in that member. The reaction between its field and that caused by the current induced in the stationary winding is sufficient to start the machines.

Several other methods of starting polyphase synchronous motors can be employed. The first of these necessitates the use of a polyphase induction motor, belted to the shaft of the synchronous motor. It will be seen farther on that induction motors are self-starting, and a machine of this type and of small capacity can be used for the purpose mentioned. When the synchronous motor is running at full speed, it is synchronized with the supply circuit as any

alternator would be, and the belt from the induction motor is then thrown off.

Another method of starting a synchronous motor, which is employed only in case the motor forms part of a rotary transformer, involves the employment of the direct-current side of the machine. The latter winding enables the machine to be run as a direct-current motor, enabling the alternating side to be synchronized with the supply circuit, as before. From the foregoing it will be seen that polyphase synchronous motors are not to be used where machines requiring a large starting torque are required. Their essential quality of operating at absolutely constant speed (supposing the frequency of the supply circuit to be constant) makes their use in many cases indispensable.

INDUCTION MOTORS.

72. Single-Phase Motors.—The lack of the power of self-starting under load in synchronous motors led to the development of a type of motor known under the above head. Induction motors, in the same way as synchronous motors, can be divided into two general classes: (1) single-phase, and (2) polyphase.

The operation of an induction motor, whether single or polyphase, rests essentially on the existence or assumption of a rotating magnetic field.

Until a few years ago, a single-phase, self-starting induction motor was practically unknown in commercial work.

In discussing induction motors, some writers employ the terms *field* and *armature* in the same relation to the supply circuit that exists in a direct-current machine. To avoid confusion, however, we shall refer to the *armature* as the *revolving* member and the *field* as the *stationary* member, irrespective of line connections.

73. The field of a single-phase induction motor is wound exactly the same, in principle, as that of a direct-current machine. The field core, as well as the armature core, is

laminated instead of being solid, and is so made to reduce loss from hysteresis and eddy currents.

The armature of a single-phase induction motor is, in most cases, the same as that employed in polyphase induction motors. By referring to Fig. 36, an idea of its construction can be obtained. There is a laminated core provided with a number of slots. In these slots are placed copper bars *b, b, b*, insulated from the core by means of insulating

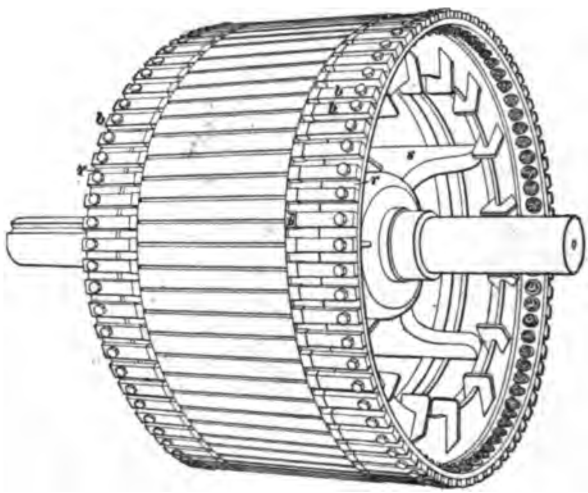


FIG. 36.

troughs *i*. The ends of the copper bars are connected together by means of the copper rings *r, r*. The whole construction resembles a squirrel cage, and this form of winding is therefore known as the *squirrel-cage winding*. The alternating magnetism in the field sets up current in the armature, and the reaction between the two causes a repulsion. This does not evince itself as useful torque, as the forces are balanced. If, however, the armature is given a start (by hand) *in either direction*, it will increase in speed till such a speed is reached that the slip is just sufficient to allow the proper working current to be induced in the armature. An increase in load will cause the armature to drop slightly in speed.

74. It has been said that a motor with an armature of this type is not self-starting. As far as practical requirements are concerned, a motor of this type would do little towards supplying the demand.

The motor shown in Fig. 37 is one made by the Wagner Electric Manufacturing Company, and has the property of self-starting. The field is of the usual type, described as follows: The armature is provided with a distributed winding. In

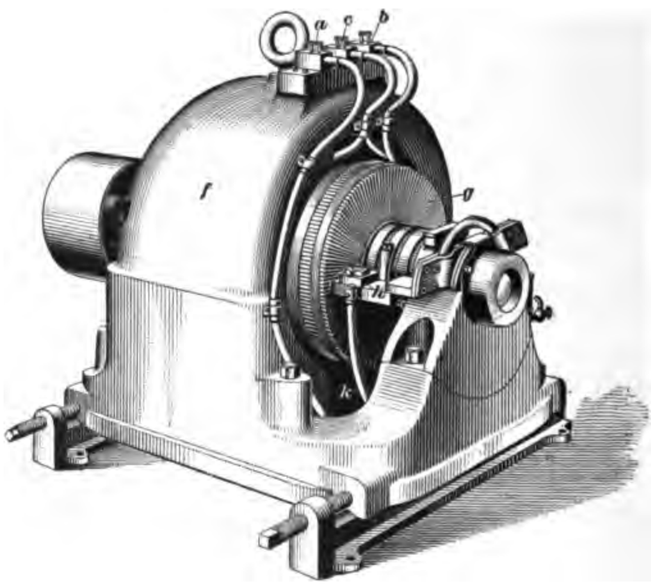


FIG. 37.

starting, the field is connected to the supply circuit, and the induced currents in the armature, instead of being allowed to circulate at will, as in the squirrel-cage type, are controlled by means of short-circuited brushes, one of which can be seen at *h*, Fig. 37. The reaction between armature and field causes a repulsion as before, one component of which acts tangentially on the armature, causing it to revolve with considerable torque. When the proper speed has been reached, a pair of centrifugal weights concentric with the shaft lift the brushes from the commutator and

introduce at the same time a copper ring into the center of the commutator, completely short-circuiting the latter. By this means the armature winding is converted into one of the squirrel-cage type, and the machine, therefore, continues to operate. This machine can be made to start with even more than full-load torque by cutting out part of the field winding. This is done by connecting the line-wires to binding-posts *a* and *c*, in place of *a* and *b*.

The direction of rotation in a Wagner single-phase induction motor can be changed by shifting the brushes a slight amount forwards or backwards.

POLYPHASE INDUCTION MOTORS.

75. In a great many cases it is necessary to have an alternating-current motor which will not only start up of its own accord, but one which will start with a strong torque. This is a necessity in all cases where the motor has to start up under load. It is also necessary that the motor be such that it may be started and stopped frequently, and in general be used in the same way as a direct-current motor. These requirements are fulfilled by *polyphase induction motors*, which have come largely into use, especially in sizes up to about 100 or 150 H. P.

76. Polyphase induction motors are usually made for operation on two or three phase circuits, although they are sometimes operated on single-phase circuits, as explained later. They always consist of two essential parts, namely, the *primary*, or field, to which the line is connected, and the *secondary*, or armature, in which currents are induced by the action of the primary. Either of these parts may be the revolving member, but we will suppose in the following that the field is stationary and the armature revolving. In a synchronous motor or direct-current motor, the current is led into the armature from the line, and these currents reacting upon a fixed field provided by the stationary field-magnet produce the motion. In the induction motor, however, two or more currents differing in phase are led into

the field, thus producing a magnetic field which is constantly changing and which *induces* currents in the coils of the armature in the same way that currents are induced in the secondary coils of transformers. These induced currents react on the field and produce the motion of the armature. It is on account of this action that these machines are called induction motors.

FIELD WINDING.

77. The winding on the field of an induction motor is almost exactly the same as that on the armature of a syn-

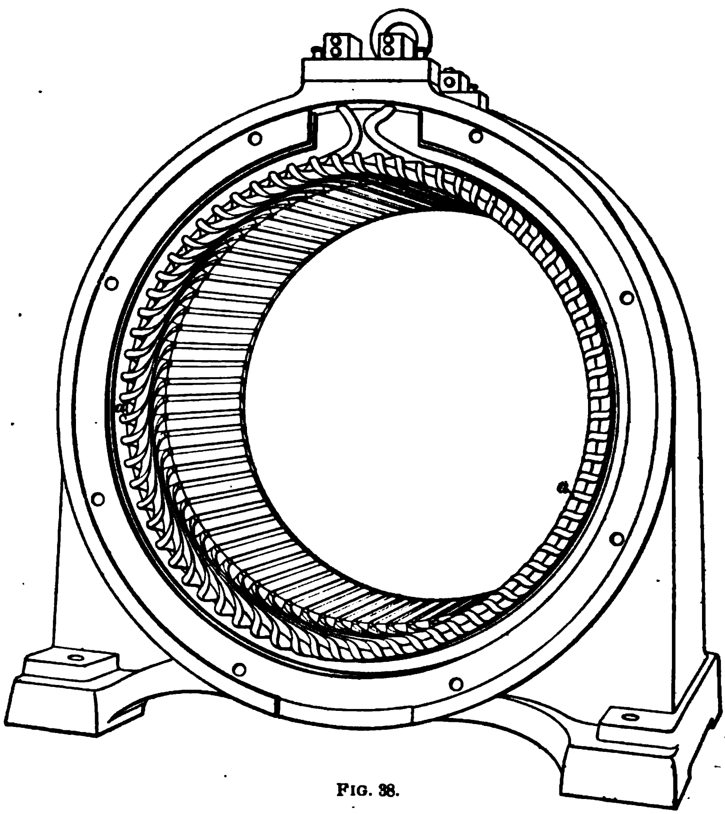


Fig. 38.

chronous motor. The field structure is built up of disks

with teeth on their inner circumference, which form slots when the core is assembled. The coils are placed in these slots, forming a winding like that on the surface of a polyphase armature. Distributed windings are usually employed; that is, there is generally more than one coil per pole per phase, and the winding when completed resembles very much the evenly distributed arrangement of coils on a continuous-current armature. Fig. 38 shows a finished field for an induction motor. The coils are seen at *a*, *a* distributed evenly around the inner circumference.

78. The action of the out-of-phase currents in producing a changing field will be understood by taking the case

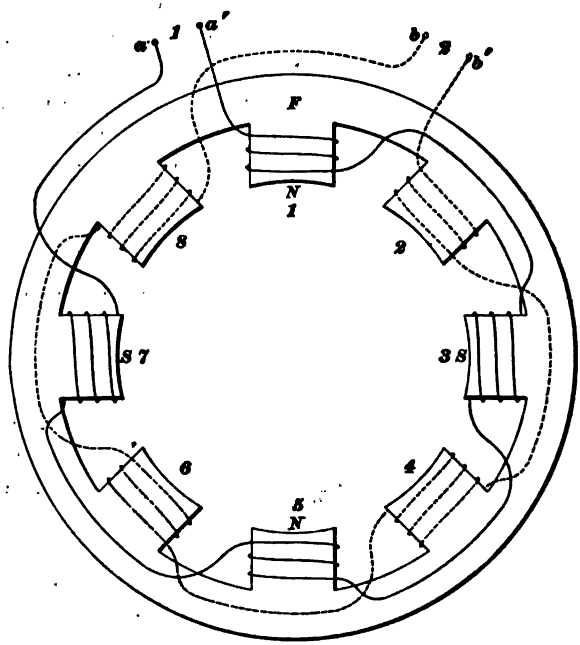


FIG. 39.

of a simple two-phase field, as shown in Fig. 39. In order to make the action clearer, we will suppose that the coils are wound on projecting poles instead of being sunk in slots.

The field F composed of laminations has eight polar projections, four poles for each phase. Each projection is wound with a coil, and alternate coils belong to the same phase, the winding constituting phase *1* being shown full and phase *2* dotted. The winding is such that if a current is sent through either of the windings, the poles formed are alternately north and south; for example, *1*, *3*, *5*, *7* would be N and S, as shown. If such a field were connected to a two-phase alternator, currents would be induced in each of the circuits, differing in phase by 90° and continually reversing in direction. The effect of this is that as the magnetism in, say, pole *1* dies out, it increases in pole *2*, and so on, thus producing the effect of a field continually shifting around or revolving. In fact, the field produced by the field coils shifts around in the same way that the field is made to shift around the armature of the alternator by its rotation in the field produced by the separately excited field-magnets. This gives, then, the effect of a four-pole revolving field; the speed at which it revolves would depend upon the frequency of the alternator. In this case, if the frequency were 60, the field would make $S = \frac{2 \times 60}{4} = 30$ rev. per sec., or 1,800 R. P. M. The effect of the distributed winding in Fig. 38 is more uniform than that in the simple motor shown above, and causes the motor to exert a more even torque.

79. Suppose an armature having also eight polar projections to be placed inside the field of Fig. 39. Each of these projections is wound with a coil c, Fig. 40, and these coils form independent closed circuits, since their two terminals are united at the points d. When a current is sent through the field, a varying magnetic flux is set up through the armature coils, thus generating an E. M. F. in them. Since the coils form closed circuits, the induced E. M. F. causes currents to be set up in them, and this causes the armature to rotate by the reaction of these currents on the field. If the armature were held from turning, the coils on the armature would act like the secondary of an ordinary

transformer, and heavy currents would be set up in them. However, as the armature comes up to speed, the relative motion between the revolving field and armature becomes less, and the induced E. M. F.'s and currents become smaller, because the secondary turns do not cut as many lines of force as before. If the armature were running exactly in synchronism with the field, there would be no cutting of lines whatever, no currents would be induced, and

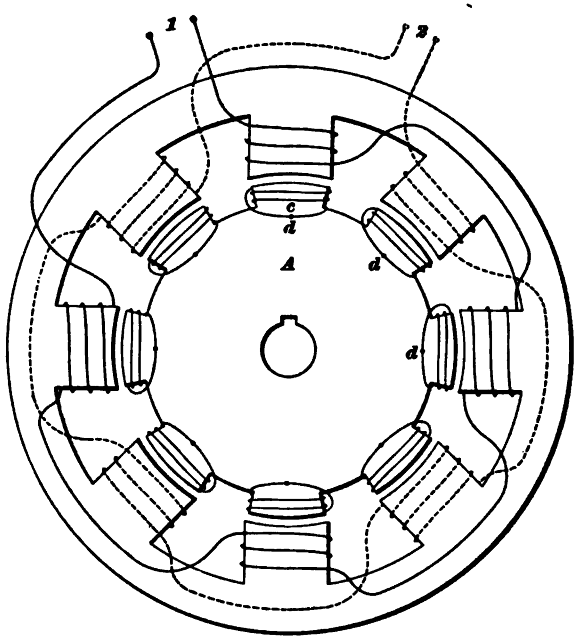


FIG. 40.

the motor would exert no torque. Therefore, in order to have any induced currents, there must be a difference in speed between the armature and the revolving field, and the greater the current and consequent torque or effort, the greater must be this difference. When the load is very light, the motor runs almost exactly in synchronism, but the speed drops off as the load is increased. This difference between the speed of the armature and that of the field for any given

load is called the **slip.** The slip in well-designed motors does not require to be very great, because the armatures are made of such low resistance that a small secondary E. M. F. causes the necessary current to flow. In well-designed machines it varies from 2 to 5% of the synchronous speed, depending upon the size. A 20-H. P. motor at full load might drop about 5% in speed, while a 75-H. P. motor might fall off about $2\frac{1}{2}$%. For example, if an 8-pole motor were supplied with current at a frequency of 60, its field would revolve $\frac{60}{4} = 15$ rev. per sec., or 900 R. P. M., and its no-load speed would be very nearly 900. At full load the slip might be 5%, so that the speed would then be 855 R. P. M. It is thus seen that as far as speed regulation goes, induction motors are fully equal to direct-current shunt machines.

That member of an induction motor to which the working current is led and in which the rotating field is produced is by some writers called the field, irrespective of its use as a stationary or rotating member of the motor. In single-phase induction motors, the field is invariably the stationary member, or, as it is sometimes called, the *stator*. In regard to polyphase induction motors, we have thus far considered only that type in which the rotating field is produced in the stationary member. In another type, in which the armature is wound similarly to that of a polyphase alternator, current is delivered to the winding by means of collector rings. In this type of machine, the relation between the rotating field produced in the armature and the consequent direction of rotation differs somewhat from that in the type heretofore considered, in which the rotating field is produced in the stator. In the second type of machine just mentioned, the rotating member is sometimes referred to as the *field*, for the reason that the rotating field is produced in it. To avoid confusion in the application of the terms *field* and *armature*, it is sometimes well to refer to the rotating member as the *rotor* and the stationary member as the *stator*, as mentioned before. In a polyphase induction motor, the winding in which the rotating field is produced encloses, or is enclosed by, another winding, whose conductors will be

cut by the lines of force of the rotating field, and an E. M. F. will be set up in them, and if their circuit is completed, a current will flow through them. This current will react on the moving field, the tendency of this reaction being *to cause the magnetic field to become stationary with respect to the external conductors.* That is, if the rotating field is produced in the rotor, and the latter is held stationary and the external conductors are free to move, they will revolve in the *same* direction that the field moves; while if, in the same case, the stator is fixed and the rotor is free to move, the armature will rotate in the opposite direction to that in which the field moves.

ARMATURE WINDING.

80. A form of armature winding for polyphase induction motors was described in Art. **73** and illustrated in Fig. 36. In some cases, especially in the larger motors, it is best to have the armature winding so arranged that a resistance may be inserted in series with it while the motor is starting up, and cut out when full speed is attained. If this is not done, there will be a large rush of current at starting, because when the motor is standing still it is in the condition of a transformer with its secondary short-circuited, and since the armature is stationary with regard to the field, a fairly high E. M. F. may be induced, thus causing a very heavy current to flow through the low-resistance secondary winding. This would cause a large current to flow in the primary, and would therefore be objectionable. Moreover, this large secondary current reacts on the field produced by the primary so as to greatly weaken it, and results in a very small starting torque. If the armature were so designed as to have a fairly high resistance in itself, in order to limit the starting current and procure a good starting torque, the motor would be inefficient and would give bad speed regulation. It is therefore best to have a resistance which may be placed temporarily in the circuit and then cut out. This may be done by supplying the secondary with a regular winding similar to that of the field

and bringing the terminals to collector rings. By means of these, connection may be made to a resistance-box, and resistance cut in or out in much the same way as is done in starting up direct-current motors. In the General Electric Company's motors, the use of collector rings is avoided by mounting the resistance on the armature spider, and cutting it out by a switch operated by a sliding collar on the shaft.

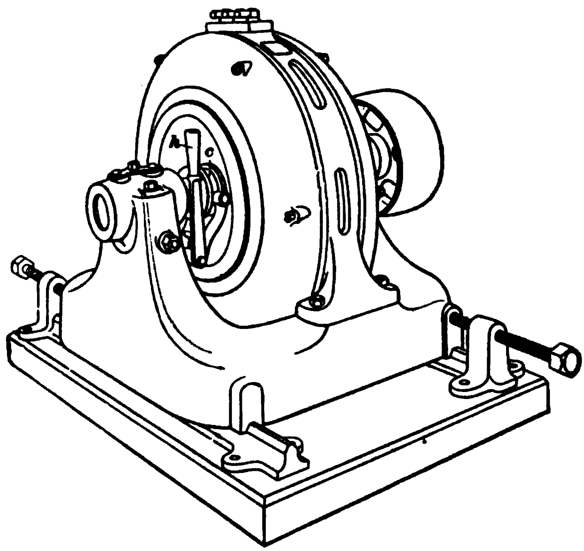


FIG. 41.

This enables the motor to be built without any moving contacts whatever. Fig. 41 shows one of the above motors with adjustable resistance in the secondary, the handle *h* shown in the figure being used to operate the sliding collar *c*. It also shows the arrangement of the parts of a motor with stationary field and revolving armature.

81. In cases where it is necessary to have induction motors run at variable speeds, it is usual to supply them with collector rings connected to an adjustable rheostat, a method often used where such motors are intended for operating hoists, etc.

The direction of rotation of the revolving field produced in a polyphase induction motor can be changed by reversing one of the phase connections.

82. Induction motors are always constructed with a multipolar field, so as to keep down the speed of rotation. The number of poles employed increases with the output, and the speed is correspondingly decreased. The following table gives the relation between poles, output, and speed for some of the standard sizes of induction motors (60 cycle).

Poles.	H. P.	Speed.
4	1	1,800
6	5	1,200
6	10	1,200
8	10	900
8	20	900
10	50	720
12	75	600

PHASE SPLITTING.

83. Motors are sometimes operated from single-phase circuits by splitting the phase; that is, the original single-phase current may be split up into other currents which are out of phase, and thus suitable for starting up a motor. A simple arrangement of this kind is shown in Fig. 42. The motor is supplied with two windings, which are connected to the mains, one in series with a resistance R and the other in series with an inductance L. It is evident that the current in circuit B will lag behind that in A, and the motor will therefore be supplied with two currents suitable for starting. After the motor has run up to speed, R and L are usually cut out and the machine runs as a synchronous motor. A number of starting devices are in use for operating motors from single-phase machines; but where a

really satisfactory motor is required, the multiphase induction or synchronous motors are used. The latter are especially

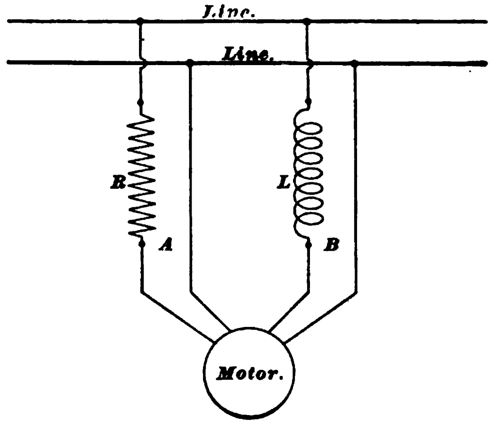


FIG. 42.

valuable for large power-transmission plants, where lagging currents are objectionable.

OUTPUT.

84. The output of an alternating-current motor, in fact of *any* motor, steam, hydraulic, or electric, may be measured by the method given in Art. **62.** As stated in Art. **39,** the ordinary methods of measuring the input to the machine can not be relied upon with alternating currents, so that special methods are required. The efficiency of good alternating-current apparatus is, however, equal to that of similar direct-current machines, and the losses are distributed in about the same proportion.

As no sparking occurs in alternating-current machinery, it obviously does not affect the output. Armature reaction, however, does affect it, as has been pointed out in the case of synchronous motors (Art. **68**). With rotary-field motors, if the load on the machine becomes so great as to

require an excessive torque, the increased current in the armature will at a certain point so weaken the field that it can furnish no increased torque, in which case the machine will stop.

The effect of the heat generated by the current in alternating machines is the same as in direct-current machines, so that the same limitations exist; that is, they should not heat to more than 80° F. above the temperature of the surrounding air.

THE INSTALLATION AND CARE OF DYNAMO-ELECTRIC MACHINERY.

INSTALLING.

85. Dynamo-electric machinery should always be located in a dry place, where the air is cool (see Art. **75,** Part 2), and where it will not be exposed to dust, especially metallic or mineral dust. Moisture will soon injure the insulation, and dust will, if metallic, often cause damage by settling in the winding or in the bearings.

For dynamos or motors up to about 30 H. P. capacity, a good, substantial floor affords a sufficient foundation. Machines of larger size should be provided with brick or stone foundations, of a size and weight depending on the size of the machine. For machines of 100 H. P. or greater capacity, the foundations should not be less than five feet deep.

The machine should be supported on a wooden subbase, resting on the foundation or floor, which should be about 8 inches high. This subbase serves to insulate the frame of the machine from the ground, so the bolts which hold it down to the foundation should be so located as not to touch the bolts which hold the base of the motor down on the subbase. The subbase should not be painted, but should be oiled or filled, to prevent it from absorbing moisture.

If the machine is driven by a belt and the belt passes a part of the frame before reaching the pulley, the static electricity generated in the belt will sometimes pass into the frame of the machine, when it is liable to injure the insulation by *jumping through* it to the winding. A path for this static electricity to escape to the ground may be made by charring with a red-hot iron a fine line on the wooden subbase, extending from one of the bolts which holds the subbase to the foundation to one of the bolts fastening the dynamo base to the subbase. A heavy pencil line drawn with a soft pencil will answer the same purpose. This will not materially affect the insulation of the machine from the ground, but will afford a path for the static electricity to escape.

It is a good plan to place a tin drip pan about 1 inch deep between the base of the machine and the subbase and large enough to catch whatever oil may drip from the bearings, thereby preventing it from soaking into the floor.

86. The foundation should be located with respect to the driving pulley or shaft, so that the length of the belt used should not be too small nor too great. Fifteen to twenty feet between centers is about right, unless the driving pulley is more than about six times the diameter of the driven, in which case longer belts should be used, so as to get sufficient arc of contact on the driven pulley to drive it without making the belt too tight.

Belted machines of the smaller sizes (less than 150 H. P. capacity) are usually provided with a *sliding bed-plate* with guides or rails on which the machine slides, it being moved backwards or forwards by screws operated by levers or hand-wheels. (See Figs. 52 and 53, Part 2.) The machine is not, then, bolted directly to the subbase, but may be fastened down on the bed-plate which is bolted to the subbase.

If a new belt is to be used, its length should be calculated for that position of the pulleys when they are *nearest together*. Then, as the belt stretches with use and becomes

slack, the machine may be slid along the guides, and the proper tension of the belt maintained.

The width of belt necessary to transmit the power to or from the machine may be calculated by the rules given in previous articles. It will usually be found that the pulley furnished with the machine is about 1 inch wider than the belt required. For machines of between 10 and 50 H. P. capacity, the belting used should be that known as *light double* or *dynamo* belting, which should be of about $\frac{3}{4}$ the width of a single belt to transmit the same power. Dynamo and motor belts should have cemented or riveted joints, to insure smooth running. Laced belts should not be used.

The size of the pulley on the engine or shaft to which the machine (dynamo or motor) is belted may be calculated from the size of the pulley and its number of revolutions, using formula $N = \frac{d\,n}{D}$. To the calculated size of the driver should be added 2%, to allow for the slip of the belt. *The size of the pulley on the machine should not be altered*, except by the advice of the makers or their representatives.

87. In the following articles upon the setting up and the testing of machines, only direct-current constant-potential dynamos will be considered. Other classes of machines will be taken up later. On setting up a new machine, the foundation and subbase should first be prepared, then the bed-plate set in position on the subbase, but not fastened. The machine should then be *very carefully* unpacked and set in position on the sliding base. Small machines, up to 10 or 15 H. P. capacity, are usually packed in a box, with the armature and field coils in position and connections made, so it is only necessary to take them out of the box and set them upon the bed-plate.

Machines from 15 to about 50 H. P. capacity usually have the armature removed and packed separately, the field coils being left on the frame, which is boxed. Still larger machines usually have the armature, field coils, connection

boards, rocker-arm, etc., removed and packed separately, and the frame skidded.

When this is done, the bearings, joints in the magnetic circuit, and similar bright surfaces are slushed with grease or painted with thick white-lead paint; this should be cleaned off, using benzine or kerosene oil for the grease and turpentine for the paint. Joints in the magnetic circuit should be wiped off with a cloth, not with waste, for the latter will catch on the tiny points on the surface of the iron, and will prevent the two surfaces from coming tightly together.

Most machines of the larger sizes are now made multipolar, and the top part of the magnetic circuit may be removed, down to the center line of the shaft, to allow of removing and replacing the armature. Others have the magnetic circuit solid, but the standards are made removable, so that the armature may be slipped out endways. If there is little headroom, it is desirable that the machines have both the upper part of the magnetic circuit and the standards removable, so that the armature needs to be lifted only 2 or 3 inches, instead of more than half its diameter, as would be the case with standards cast solid with the base.

88. After cleaning up the bearings and joints, the lower half of the machine should be set up in position on the bedplate, and the field coils and the pole-pieces (if removable) placed in position, care being taken to get the field coils on in the right *order* and *position*, so that they will connect together properly.

If the bearings are *self-oiling*, the cavity in the standard which contains the oil should be examined to see if all the sand from the mold in which it was cast has been removed. If this has not been done, it should be blown out with a hand bellows, or, better, with a jet of live steam from the boilers, if that is obtainable. The caps for the standards should be examined and cleaned in the same manner. The bearings should then be wiped out, cloth being preferable to waste for this purpose also.

After this has been done, the armature should be looked over to see if the winding and commutator are uninjured, and all dirt or sawdust should be brushed or blown out of the spaces between the coils, etc.: it should then be placed in position in the bearings.

89. As it is very important not to bump the armature against the projecting corners of the machine in putting it in place, it should not be lifted in by "main strength," if so heavy that two men can not handle it readily, but a crane or other hoisting mechanism should be used.

To lift the armature, a rope sling should be used, which should be looped around the ends of the armature shaft, never around the commutator. To this sling, the hook of the tackle, or chain block, may be fastened, and to prevent the sling from bearing against and possibly injuring the armature winding or the commutator, a piece of board, notched at the ends, should be placed between the two parts of the sling.

This is represented in Fig. 43, *B* being the notched piece of board and *S* the sling. The sling should be crossed in the hook, as represented, for otherwise it is very liable to slip and drop the armature.

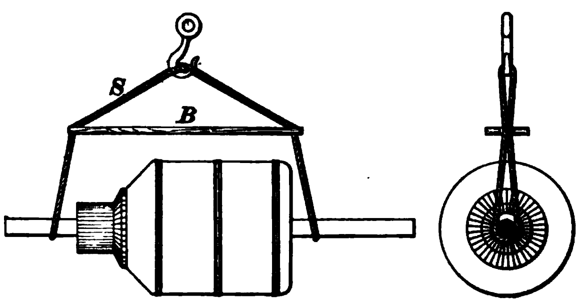


FIG. 43.

A single chain block, or tackle, is not desirable to use in handling a heavy armature, as, either in raising or lowering, the armature must be swung out to one side, which is very inconvenient, and the armature is liable to swing

around unexpectedly and damage itself by bumping against the frame. If an overhead traveler is not at hand to attach the tackle to, two tackles should be used, one hung directly over the center of the machine, and the other directly over the nearest point on the floor to which the armature can be brought.

The armature may then be lifted by this latter tackle until high enough to clear the frame of the machine, when the other tackle may be hooked on, and by slacking off on the one and hauling in on the other, the armature may be lowered directly into place. In this way, two men can easily handle a heavy armature.

The top part of the magnetic circuit or other heavy parts of the machine may be put in place in the same manner.

If the armature winding is on the surface of the core, it should not be rested directly on the floor, but on a pad of waste or rags, or the end of the shaft should be supported on a couple of wooden horses. If the armature is of the "ironclad" type, in which the winding is embedded in slots cut in the periphery of the core, this precaution is not necessary. In either case, the armature should always be *lifted* by means of the shaft.

After placing the top part of the magnetic circuit with its pole-pieces and field cores in position and setting up the bolts or screws which hold it in place, the bearings should be filled with oil and the armature turned over a few times by hand to make sure that it does not touch the pole-pieces at any point and that the shaft runs easily and true; if it binds at any particular point of a revolution, the shaft may have been sprung in transit, and it should not be run in that condition. The armature shaft should have an end play of from $\frac{1}{4}$ to $\frac{1}{2}$ an inch, except in those machines in which the pole-pieces face the end surface of the armature, like the Brush constant-current machine. This end play allows of a slight end motion of the armature as it runs, which makes the wear on the commutator and bearings more uniform, and prevents the shaft from sticking by any slight endwise expansion it may undergo.

TESTING, AND LOCATING AND REMEDYING FAULTS.

90. If everything appears to be all right, the pulley should then be put on and the machine carefully lined up with the shaft and pulley to which it is to be belted, and the bed-plate fastened permanently to the subbase. Then the belt should be put on and the machine run without load and with no field excitation for two or three hours, if possible, to make sure that the bearings and oiling arrangements are in working order.

If the bearings begin to heat badly, the oil in the bearings should be examined to see if it is gritty, and if so, it should be drawn off and fresh oil substituted. *Only the best grades of light mineral oil should be used;* any cheaper oil costs more in the end. If the bearings still heat, they should be taken out and examined for rough spots, and if necessary, scraped.

If taken in time, the corresponding roughness of the journal may be removed in the following manner: Take a piece of crocus cloth of a width equal to the length of the journal, wet it with oil, and wrap it around the journal; then take a turn around the journal with a piece of cloth tape or strip of cloth, take one end of the strip in each hand, and by alternately pulling on each end rotate the piece of crocus cloth around the journal, which will effectually polish it and remove all slightly rough spots. If the shaft has been bruised or dented, the high spots should be carefully brought down with a fine file before polishing with the crocus cloth.

If self-oiling bearings are used, they should be examined to see if the rings turn freely; if they show a tendency to hug the sides of the slots in the bearings, and turn very slowly, or not at all, they should be bent a trifle, so that all parts of the ring do not lie in the same plane, and so that as they turn they will run from side to side of the slots in the bearings. This may usually be done with a pair of heavy pliers or a small wrench, without removing the bearings from the machine. It should be carefully done, and the

"wind" of the ring made uniform, so that it will not catch in the slots at any point.

If a new belt is used and it has been made of the proper length, it will usually be tight enough to cause the bearings to get hot at first, but in half an hour or so it will stretch sufficiently to relieve the pressure, and the bearings should cool off. Large belts that are made endless by the manufacturers are usually stretched by them, in which case they should be put on without quite as much tension as an unstretched belt. (See Art. **86.**)

91. If the machine runs all right, it should then be prepared for a run under load. Before stopping the machine, the commutator should be examined for high or low bars or rough spots, by touching it lightly with the finger nail or the end of a lead-pencil all along its length, as it turns, which will show if the above defects exist. Rough spots can be removed with sandpaper (*never* emery-paper or cloth) folded around a bit of board and pressed evenly on the commutator as it turns. High or low bars, or "flats," can only be removed by turning the commutator down to a uniform diameter, using for this purpose a sharp **V**-pointed tool, a fine feed, and a high speed, finishing with fine (0 or 00) sandpaper or a smooth file.

After the commutator has been turned up, it should be carefully gone over to see that the tool has not left chips that have become embedded in the insulation between the bars. If any such exist, they should be carefully picked out and all copper dust wiped or blown off the commutator and armature.

The yoke and brush holders should then be placed in position, and the brushes, if not of the radial type, carefully adjusted, so that they bear on the commutator the proper distance apart. This may be done by counting the commutator segments, and dividing their number by the number of poles, the result being the number of segments which should lie between the tips of successive sets of brushes. Some multipolar machines use only two sets of brushes, but

the fraction of the circumference of the commutator that separates the two is indicated by the rocker-arm.

It is often convenient to make marks by means of a prick punch on the end of the commutator shell, which will indicate the segments on which the various sets of brushes would rest when the proper distance apart. These reference marks will serve to relocate the brushes at any time.

The brushes should bear evenly on the commutator throughout their whole end surface. Metallic brushes are usually flexible enough to take care of this point, but carbon brushes should be fitted to the commutator surface. This may readily be done by putting them in position in the brush holders, and dragging a sheet of medium-fine sandpaper back and forth between the brushes and the commutator, keeping the paper side of the sandpaper down on the commutator; this will grind the ends of the brushes down to the same curve as that of the commutator.

The tension used on the brushes should be uniform—light with metallic and heavier with carbon brushes.

Machines which are shipped with the connections broken are usually accompanied with a diagram showing the proper method of connecting them up; if this is not the case, some one perfectly familiar with the apparatus should make the connections. In any case, the connections should be carefully looked over to see if they are all right, and all screws, binding-posts, and other connections fastened firmly.

92. The machine should then be run up to its proper speed, the brushes placed in the approximate neutral position, the shunt-field circuit closed, and the resistance gradually cut out. If everything is all right, the machine will build up to its proper voltage (see Art. **37,** Part 2); but if this does not occur, the trouble may be looked for as follows: Attach a voltmeter to the brushes, with the field circuit *open;* the voltmeter should show a slight deflection, due to the E. M. F. generated by the residual magnetism. Then close the field circuit, and if the voltmeter needle goes back towards zero, it shows that the *current sent around*

the field coils by the E. M. F. due to the residual magnetism tends to magnetize the fields in the opposite direction, so that the few lines of force of the residual magnetism are opposed and destroyed, and the machine can not build up.

If this seems to be the case, rock the brushes ahead or back until any one set occupies the position formerly occupied by its neighbor. Then close the field circuit again, and if this is the only trouble, the machine will build up. If it does, and this position of the brushes is inconvenient for any reason, they may be put back in their former position and the connections of the shunt fields reversed.

If the machine still does not build up, it may be due to the absence of any residual magnetism, in which case the current from a few cells of battery or another dynamo sent through the coils will establish a sufficient amount to enable the machine to build up. The presence (or absence) of residual magnetism may be shown by a voltmeter, as described above.

If this is not the trouble, the field circuit may be broken somewhere. Examination of the connections between the various coils will show if they are defective or loose; quite frequently the wire in the leads from the spools becomes broken at the point where they leave the spool, while the insulation remains intact, so that the break does not show. This may be readily detected by "wiggling" the leads.

If the break is inside the winding of one of the coils, it can only be detected by testing out each coil separately to see if its circuit is complete. This may be done with a Wheatstone bridge (Art. **53**, Part 1) or with a few cells of battery and a galvanometer. A low-reading Weston voltmeter makes a good galvanometer to use for this purpose.

If the current from another dynamo can be obtained, the faulty spool may be detected by connecting the terminals of the field circuit to the terminals of the circuit of the other machine; no current will flow through if the circuit is broken, but if a voltmeter is connected across each single field coil in succession, it will show *no deflection* if the coil is continuous, because both poles of the voltmeter will be

connected to the *same* side of the dynamo circuit. If the coil has a break in it, one of its terminals will be connected to one side of the circuit and the other to the other side, so that a voltmeter connected between these terminals would show the full E. M. F. of that circuit. Consequently, when the voltmeter is connected across a spool and shows a considerable deflection, that spool has an open circuit which must be repaired before the dynamo can operate.

93. This method of testing is represented by the diagram, Fig. 44; *1*, *2*, *3*, and *4* represent the field coils of a 4-pole dynamo, there being a break in coil *2* at *B*. The terminals *a* and *e* of the field winding are connected to the + and − terminals of a "live" circuit; that is, a circuit connected to a dynamo in operation. It will be seen that terminals *a* and *b* of coil *1* are both connected to the + side of the circuit, and as there is no current flowing through the field circuit, there is no difference of potential between *a* and *b*; therefore a voltmeter connected to *a* and *b*, as at *V*, will show no deflection. But terminal *c* of coil *2* is connected to the − side of circuit, so a voltmeter connected to *b* and *c*, as at V_1, will show a deflection, and in fact will indicate the difference of potential between *a* and *e*.

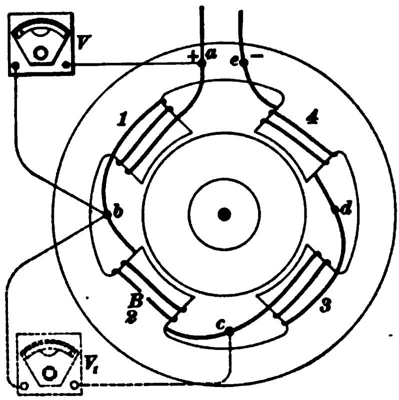


FIG. 44.

The above test may be roughly made with a bit of wire long enough to span from terminal to terminal of a coil. If one end of the wire is touched on *a*, for instance, and the other on *b*, it will not affect the circuit any; but if touched on the terminals of the coil in which the break is located, the field circuit will be completed through the bit of wire, and a spark will occur when the wire is taken away. The

wire should not be allowed to span more than one coil at a time, otherwise it may short-circuit so much of the field winding that too great a current would flow.

94. If the machine builds up to about half its normal voltage or less, and refuses to come up higher when all the external resistance is cut out of the field circuit, the trouble may be due to too low speed, which may be easily tested by counting the number of revolutions made by the machine. If this is not the fault, the brushes should be rocked back and forth, and if the voltage increases with a motion of the brushes in either direction, this motion should be continued until the voltage will not increase further, in which case the brushes are probably in the proper neutral plane.

If the voltage is still considerably too low, it is probable that one of the field coils is wrongly connected, so that the fields are not all of the proper polarity. This can be tested with a small compass, and if one field is found to be of the wrong polarity, the connection of its coil should be reversed, in which case the machine will probably build up properly, unless there is some serious defect in its construction.

When the machine has built up to its proper voltage, and the brushes have been adjusted to the non-sparking position, the armature should be examined for *short circuits.* These occur when the ends of one of the coils form accidental contact with each other, or when two neighboring wires touch each other; the effect in either case is to form a closed circuit of one or more active conductors, which circuit, being of low resistance, has an excessive current generated in it, causing it to heat badly, and finally destroying its insulation.

This fault may be detected by holding a nail, screwdriver, or other small piece of iron over the surface of the armature between the poles. The fluctuations in the current flowing in the short-circuited coil, as it passes from one pole to another, set up corresponding fluctuations in the stray field between the pole-pieces, so that the piece of iron held in this stray field will be vibrated quite strongly. Care

should be taken not to allow the bit of iron to be pulled into the armature by the attraction, as that would probably destroy the winding.

95. Armatures in which the winding is embedded in slots cut in the periphery of the core will sometimes cause a piece of iron held between the poles to vibrate, especially if the slots are comparatively few in number; but this action can be readily distinguished from that due to a short-circuited coil, as the vibrations due to the teeth on the armature occur several times in a revolution, while those due to the short-circuited coil occur only once in a revolution. The difference in the rate of the vibration may be easily distinguished.

If a short-circuited coil appears to exist, the machine should be run for some time (with no external load), perhaps ten minutes, and then shut down. By feeling all the armature coils in succession on the back end of the armature, the defective coil may be readily picked out by its being much hotter than the others. It should then be marked in some way and the armature taken out and the coil rewound or the short circuit otherwise removed.

96. If the armature shows no short circuit, it should be run under load for some time before being put regularly in commission. It is usually not desirable to connect it for this test to the circuit which it is to supply with current, since the load can not be readily controlled. It is better to provide an artificial load for the machine which may be readily controlled, so that any desired load may be obtained.

With small machines of the proper voltage, this artificial load may be made by using a **lamp bank**; that is, a number of incandescent lamps arranged so that few or many may be connected in circuit by manipulating the necessary switches.

With larger machines, especially of the higher voltages (230 or 500 volts), this method is not so convenient as a **water**

rheostat, which consists of a wooden tank filled with salted water, in which are hung two iron (or other metal) plates, that are attached to the terminals of the dynamo. The circuit is thus completed through the water between the plates, and by varying the distance between the plates, the resistance of the external circuit can be adjusted between wide limits.

An old oil barrel makes a good tank if the dynamo to be tested has an output of not more than about 15 kilowatts. If a greater amount of energy must be disposed of, the surface and the amount of the water must be greater than a barrel will afford, and a tank should be made for the purpose, especially if several machines are to be tested. Fig. 45 illustrates a form of water rheostat, in which T is the

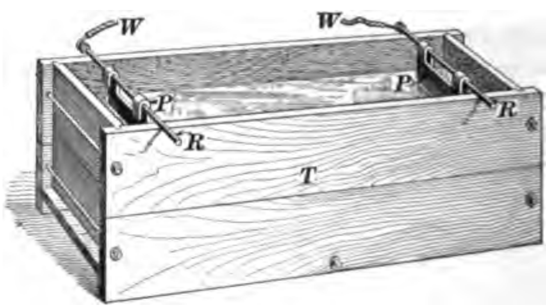


FIG. 45.

wooden tank, which should be about 7 feet long and about $2\frac{1}{2}$ feet square, inside measurements, made of $1\frac{1}{2}$-inch or 2-inch pine plank, with tongued-and-grooved joints, which should be leaded to make them tight, the whole being held together by cross-bolts, as represented in the figure.

Two iron rods R, R are placed across the top of the tank, and to them the terminals of the dynamo circuit are attached, as represented at W, W. From these rods two iron plates P, P are hung, which should have about $3\frac{1}{2}$ or 4 square feet of surface (on one side) below the water-level. These plates may be made of a couple of pieces of old boiler-plate or heavy ($\frac{1}{4}$-inch or thicker) sheet iron, cut with two

projecting lugs on the top, which are bent into hooks by which the plates are hung from the rods *R*, *R*. Cast iron will do equally well; two old ash-pit doors, for example, will make very good plates, the rods being passed through the holes for the hinge pins.

When ready for use, the tank should be filled with water, and from 5 to 20 pounds of rock salt or washing-soda added to reduce the resistance to the required figure, as water alone would give altogether too high a resistance. The resistance should be made such that when the two plates are at opposite ends of the tank, about $\frac{1}{10}$ the normal current of the generator will flow when the circuit is closed. An ammeter should be connected in circuit with the rheostat, of a capacity sufficient to measure the full-load current of the machine.

When all preparations are completed, connections firmly made, and the plates at opposite ends of the tank, the external circuit should be closed and the plates moved closer together, until the current is about one-quarter the full-load current of the machine. The machine should then be examined for further faults, which will generally be indicated by sparking at the brushes.

97. If the brushes spark badly, they should be shifted backwards and forwards a little, and the position of least sparking found. If they are too far back, the spark will occur at the forward tips of the brushes, and will generally, especially with copper brushes, be short, bluish in color, and confined to one or two points along the row of brushes in each set. If too far forwards, the spark will appear to come from *under* the brush, will generally be more yellowish in color, and will occur all along the rows of brushes.

Even when in the best position, the sparking will not entirely disappear, for by looking carefully under the brushes, a tiny twinkling spark will be seen, which, however, does no damage.

If there is an intermittent sharp flash at the brushes, occurring at each brush once in a revolution, it is probably

due to an *open circuit* in the armature winding, which usually occurs in the leads from the armature coils to the commutator segments. The break may be located by running the armature and allowing it to flash for half a minute or so, when it will be found that one, perhaps two, commutator bars are noticeably burned, the burn extending from the *forward* edge of the bar (in the direction of rotation) back half its width or more. The armature head should then be removed and the lead from the winding to the burned bar examined.

If the lead is only disconnected from the bar by having become unsoldered or by the wire slipping out from under the screw which holds it, the fault may be quickly repaired. If it is necessary to resolder the connection, care should be taken that particles of the solder do not fall on the back of the commutator in such a way as to connect two bars or two leads together, or to connect a commutator bar with the shell. *Acid should not be used* in soldering these connections, since the acid will corrode the joint and finally cause a break; the surfaces should be scraped bright and resin used as a flux. Resin dissolved in alcohol makes a very convenient flux for this kind of work.

If the break is such that it can not be readily repaired, and there is not time to put in a new connecting wire, the machine may be temporarily used by connecting the burned bar with either of the adjacent bars by a drop of solder, or by hammering lightly on the *end* of the bars until the space between the two is bridged over by the soft metal. *This should never be done* if possible to repair the broken connection, but will sometimes be necessary in case of an emergency. When the break is repaired, which should be as soon as possible, the connection between the bars must be removed.

When the break is in the connection between the winding and the commutator bars, the continuity of the winding is not usually disturbed, since the leads to the commutator do not usually form a part of the winding. In case the break is in the coil itself, the expedient described above can not be used without affecting the capacity of the machine, and the

break must be located and repaired, which will usually require the rewinding of the broken coil.

A high bar or a "flat," and sometimes a *badly* short-circuited coil, will cause a flashing similar to that due to an open circuit, but these should have been looked for and remedied before, as described in Arts. **91** and **94.** If none of the above troubles develop, the load on the machine should be gradually increased by moving the plates of the water rheostat closer together, until the current is as great as the rated capacity of the machine will allow.

98. If the dynamo is compound wound, the voltmeter should be watched as the load is increased, to see if the compounding is of the correct amount. If the voltage falls off rapidly as the load is increased, the series coils are probably connected wrongly, and their connection should be reversed, when the voltage should remain constant or slightly increase as the load increases, without changing the resistance in the shunt-field circuit.

The brushes should be carefully shifted as the load increases, if necessary to prevent sparking, and the position of the brushes at the different loads noted. If the machine is to be used under a suddenly variable load, the shifting of the brushes should be slight, and in fact there should be a position of the brushes where the sparking will be nothing at medium loads, and not serious at either full load or no load, and they should be kept in this position at all times.

99. In multipolar machines with as many brushes as there are poles, the sparking between one pair of brushes may become violent as the load increases, while the others run quietly. This may be due to a wrong adjustment of the brushes, which may be readily detected and remedied; but if this is not the trouble, the series coil (in compound-wound machines) of that pole-piece between the two sets of brushes may be short-circuited or wrongly connected. This may be detected by trying the strength of that pole-piece

relative to one of the others, by noting the pull required to detach a screw-driver or other bit of iron from similar points on the two pole-pieces. If the series coil is defective, there will be a noticeable difference in the pull of the two pole-pieces, that on which the defective coil is wound being much weaker than the other.

If the series coil is connected wrongly, the error can be readily rectified, and a further test will show if this is the fault. If the coil has some of its turns short-circuited, it is difficult to locate the fault except by unwinding and rewinding the coil, which should only be done by representatives of the company furnishing the machine or by their direction.

If one of the shunt coils is affected in the same way, that is, wrongly connected or partially short-circuited, the trouble will manifest itself before the load is put on. (See Art. **94.**) If one of the coils is partially or wholly short-circuited, the field current will be greater than the normal, which will cause the *good* coils to heat excessively, while the defective coil remains cool.

While running under full load, the bearings and belt should be watched; if the bearings have a tendency to heat excessively, the belt should be slacked off, if possible. If the belt squeaks loudly in passing over the pulley, it is too slack, and if it can not be tightened without causing the bearings to heat excessively, a wider belt should be substituted, unless the heating is due to dirty oil or rough spots in the bearings. These last causes will usually show up in the first part of the run, however, when the machine is not loaded.

100. After the machine has thoroughly warmed up, it should be tested for "grounds," or connections between the winding and the frame or armature core. This may best be done with a good high-resistance voltmeter, such as a Weston, as follows: While the machine is running, connect one terminal of the voltmeter to one terminal of the dynamo, and the other terminal of the voltmeter

to the frame of the machine, as represented in Fig. 46, where T and T_1 are the terminals of the dynamo, and V and V_1 two positions of the voltmeter, connected as described above.

If, in either position, the voltmeter is deflected, it indicates that the field winding is grounded somewhere near the *other* terminal of the dynamo; that is, if the voltmeter at V shows a deflection, the machine is grounded near the terminal T_1, and *vice versa*. If the needle shows a deflection

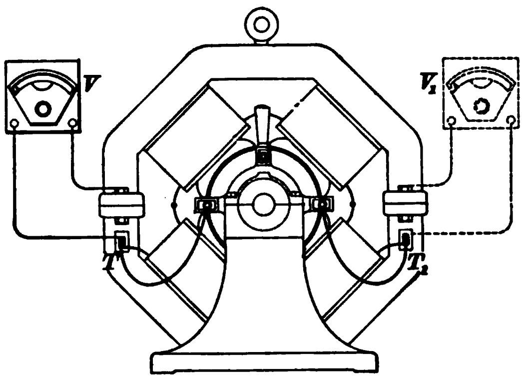


FIG. 46.

in *both* positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If, in either case, the deflection does not amount to more than about $\frac{1}{20}$ the total E.M.F. of the machine, the ground is not serious; but if the deflection is much more than this, the windings should be examined separately, the ground located, and if possible, removed.

101. To locate the ground, if thought to be in the field coils, each should be disconnected from its neighbor (with the machine shut down, of course) and "tested out" by connecting one terminal of another dynamo (or of a "live" circuit) to the frame of the machine, care being taken to make a good contact with some bright surface, such as the

end of the shaft or a bolt-head, and the other to a terminal of the coil to be tested, through a voltmeter, as represented in Fig. 47.

Here C and C_1 represent the terminals of a "live" circuit, which should have a difference of potential between them about equal to the E. M. F. of the machine when it is in operation, but also not greater than the capacity of the voltmeter will allow of measuring. T and T_1 represent the terminals of the dynamo, as before, and t and t_1, the terminals of the field coils, which have been disconnected from each other and from the dynamo terminals. One terminal C of the circuit is connected to the frame of the machine; the other terminal C_1 of the circuit is connected through the voltmeter V to the terminal t_1 of the field coil. If that coil is grounded, the voltmeter will show a deflection about equal to the E. M. F. of the circuit C C_1, but if the insulation is intact, it will show little or no deflection. The wire connecting the voltmeter with the terminal t_1 may be connected in succession to the terminal of the other coil, or coils, and to the commutator; any grounded coil of the field or armature winding will be shown up by a considerable deflection of the voltmeter needle.

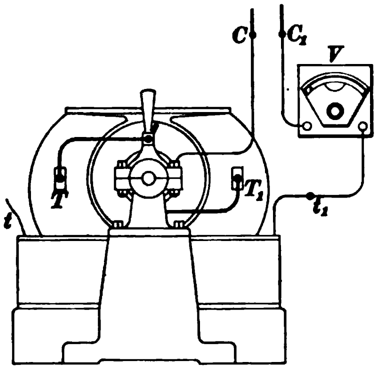


FIG. 47.

102. If the machine tests out clear of grounds, it should be shut down after the proper length of time and the various parts of the machine felt over to locate any excessive heating. If accurate results are wanted, thermometers should be used, by placing the bulb on the various parts (armature, field coils, etc.) and covering with a wad of waste or rags. They should be looked at from time to time, until it is seen that the mercury no longer rises, when the point to which it

has risen should be noted. A thermometer hung on the wall of the room will give the temperature of the air, and the difference between the air temperature and that of the various parts of the machine should not exceed the prescribed limit. (See Art. **75**, Part 2.)

When the dynamo has been found or made to be in good condition, it may be connected to the circuit which it is to supply and put in commission. The oil used in the bearings during the preliminary runs should be drawn off and a fresh lot substituted. All connection to the dynamo and to the switchboard terminals should be made firm and tight; surfaces in contact should be made bright and clean before fastening together.

DIRECT-CURRENT MOTORS.

103. In setting up direct-current motors, the same remarks apply that have been made concerning the location and assembling of dynamos. After having set up the motor and made the necessary connections to the circuit which is to supply it with power, it should be tested and run without its load, to develop any faults which may exist.

After making sure that the connections are such that when the main switch is closed or the arm of the starting box turned on to the first contact, the field circuit is closed *separately* and *before* the armature circuit (if it is a shunt motor), the current should be turned on to the field circuit, and the pole-pieces tested for magnetism with a bit of iron (a screw-driver or a nail). If they are not magnetized, and the circuit to which they are connected is *surely* "alive" (which may be tested with a voltmeter, lamps, or, if the E. M. F. of the circuit is not more than 125 volts, by lightly touching the terminals of the circuit with the thumb and finger of one hand), the field circuit is probably open, and the break should be located by the methods described in Arts. **92** and **93**. It is sometimes the case that in the style of starting box in which the movement of the contact arm first closes the field circuit and then the armature

circuit, that a particle of dirt will prevent the field-circuit contact from being made.

If the fields show that they are magnetized, then polarity should be tested with a compass, and if any one is wrong, its field coil should be reversed. When the fields are found to be of the proper polarity (with respect to each other), the armature circuit should be completed through the resistance or starting box, with the belt or other connection to the load removed, if possible.

If the motor refuses to start when the current is turned on, it should at once be examined to see if this is due to the shaft sticking in the bearings or to some similar cause which binds the armature fast. If this is not the case and the armature turns freely by hand, the armature circuit may be open in the armature, in the connections, or in the starting box. If the current is actually passing through the armature, which can be shown by lifting the brushes on one side, a slight spark showing the presence of the current, the brushes may be in the wrong position. They should be shifted backwards or forwards, when the motor will start if this is the trouble. If the fields are not magnetized, the motor will not start, except with an excessive current; this point, however, should have been previously looked into.

If the motor starts off all right, the armature should then be examined for short circuits, open circuits, defec' . commutator, etc., in the same manner as has been described for dynamos, and these faults, if they exist, remedied. When this has been done, the load should be put on the machine, and its performance carefully watched for an hour or so, to see that no defects develop themselves.

If the installation is large enough to warrant it, the temperature should be taken at the end of the run, providing the conditions are such that the motor has been subjected to as much load during the run as it is liable to get. If this is not the case, it is often desirable to make a test of its efficiency and behavior (as to sparking, etc.) under full load, using for the load a Prony brake, as described in Art. **63.**

CARE OF DIRECT-CURRENT MACHINERY.

104. The most essential feature in caring for dynamo machinery is **cleanliness.** The machine should be kept thoroughly cleaned, and oil should never be allowed to accumulate on either the armature or the field windings, as it will gradually affect the insulation.

Whenever the commutator is polished off with sandpaper, the fine copper dust should be wiped or blown off from the machine, especially from any part of the winding.

The commutator should *not* be kept bright; it is in its best condition when covered with a brownish glaze. This condition can be arrived at by carefully turning up the commutator, adjusting the brushes until there is little or no sparking, and then wiping the commutator off at frequent intervals with a cloth just moistened with oil or vaseline. Waste should not be used for wiping off the commutator, as its threads are liable to become caught in the brushes. A soft pine stick makes a very good burnisher for a commutator.

A convenient tool for wiping off the commutator may be made from a strip of heavy canvas, 3 or 4 inches wide and perhaps 18 inches long. Spread a thin layer of vaseline over one side of the cloth, roll it up like a jelly cake, and fasten the end by sewing or wrapping the roll with string. The end of this roll applied to the commutator will wipe it off and grease it to just about the right extent, and as the end becomes frayed or dirty, it can be trimmed off.

Too much oil or grease will cause the brushes to flash, long yellow sparks being thrown out from under the brush; at each point where a spark appears, a black ring will form around the commutator. which should be wiped off.

105. Carbon brushes should not be used on machines of over 10 or 15 H. P. capacity if of low voltage, i. e., 125 volts or less, as their high resistance will cause heating, owing to the large currents required. In any case they should be carefully fitted to the commutator and examined from time to time to see that the bearing surface (of the brush on the commutator) is as great as the size of the

brush will permit. When taken out after running for some time, the end of the brush should look smooth and glossy; if rather rough, grayish in color, and gritty to the touch, the carbon is "hard," and should be discarded.

It often improves a carbon brush to heat it to redness and plunge it in lubricating oil. This practice is to be recommended, as there will then be no liability of getting too much oil on the commutator, and enforced inattention will not be the cause of a poor commutator.

Metallic brushes are made of strips of copper, bundles of copper wires, or, more frequently, copper gauze folded into shape and stitched. Those made of strips or wires are very liable to have the edges or ends of the laminæ fused together by sparking, forming hard points that cut the commutator. Whenever this occurs, they should be taken out and the ends trimmed off. To get them to the proper bevel, so that they will rest evenly on the commutator at the proper angle, it is customary to use a "filing jig," which consists of a block of steel with a hole through it the size of the brush, and with one end beveled off to the proper angle and hardened. The brush is placed in the jig with the end projecting a little from the beveled face, and clamped in position by a thumb-screw. The end of the brush may then be filed or ground down flush with the face of the jig, thus giving it the correct bevel.

Metallic brushes should not be allowed to become filled with oil or dirt; if they get in this condition they may be readily cleaned with benzine or kerosene. If a commutator becomes very dirty, it may be cleaned in the same way, when the machine is not running.

This is preferable to sandpapering, so long as the commutator is smooth and round; sandpapering should only be resorted to when the commutator is rough, and not even then if there is a high bar or "flat," for in that case the only remedy is turning down the commutator. (See Art. **91**.)

106. If short circuits or open circuits develop in the armature winding after the machine is in operation, they

may be detected and remedied in the manner described in Arts. **94, 97,** and the following:

In dynamos, a break in the (shunt) field circuit will simply cause the dynamo to cease generating, and the break may be found as previously described. In shunt motors, however, a break in the field circuit will cause an excessive current to flow through the armature, and if the motor is not loaded, it will speed up excessively.

If the motor circuit is properly protected by fuses (Art. **60**), this excessive current will probably do no further damage than to blow the fuses. If not so protected, the armature will be overheated and the insulation damaged or destroyed. The break in the field circuit may be found as previously described. (Art. **93.**)

The overheating of the insulation of an armature or field coil may be readily detected by the smell.

If the coil is new and is not much overheated, the smell will be that of hot shellac; but if old, or if the coil is much overheated so as to char the insulation, the smell is very peculiar, and once experienced will not be forgotten. It is something like the smell of a strong solution of soot in rainwater. It is usually present to some extent in machines which have been running a long time, especially if their normal working temperature is high. Whenever this peculiar smell becomes apparent, the electrical machinery should *at once* be examined for some overheated part, which may be a field coil, the armature winding as a whole, or a short-circuited coil in the armature.

When the insulation of any part of a dynamo or motor has become badly charred, the part is said to be *burned out.* A burn-out requires that the part affected be replaced. A short-circuited armature coil will usually burn out in a very short time if not attended to (see Art. **95**). With short-circuited field coils, it is the *good* coil that burns out (see Art. **99**), so that in case a burn-out of one of the field coils occurs before the trouble is located, the other coils should be examined for the cause of the trouble.

REPAIRS.

107. In case of accident to parts of the machinery, it is sometimes very convenient to make repairs on the spot, saving the time lost in sending the injured apparatus to the makers.

Shunt field coils, especially of the smaller sizes, may be readily rewound in a lathe. In rewinding such a coil, the damaged wire and insulating material should be carefully removed, noticing while so doing just how they are disposed in the coil, the thickness and character of the insulating material at different points, especially on the heads and barrel of the spool, and the manner in which the leads or terminals of the coil are attached to the winding and brought out.

The size of the wire and character of its insulation (i. e., whether single or double, covered with cotton or silk) should also be carefully noted.

When rewinding the coil, all these features of the old coil should be duplicated. The number of turns of wire in the new coil should be as nearly as possible the same as in the old; this may be arrived at nearly enough by weighing the old coil before stripping off the winding, and bringing the new coil up to the same weight.

If necessary to make a joint in the wire, the ends of the wires should be rubbed bright with fine sandpaper, twisted firmly together, and soldered with a hot iron, using *only* resin as a flux. Only solder enough should be left on the joint to make the connection between the wires solid. The joint should then be covered with extra insulation, such as silk, cotton, or adhesive tape. All projecting ends of wire or drops of solder must be removed from the joint, or they will pierce the insulation and make contact with neighboring wires.

108. Armature coils require more care and experience in rewinding, so that their repair should not be attempted except in the case of the very simple forms of ring armatures, when a coil may be removed and

replaced without disturbing in the least the other coils or connections.

If it is decided to rewind a damaged coil, the binding wires should first be removed by filing them through at some point where the winding will not be injured. The number, size, and material of the wires in each band, and the character and thickness of the insulation used between the bands and the winding should be carefully noted.

The damaged coil should then be carefully disconnected from the others and removed, noting the exact number and arrangement of the turns in the coil, the thickness, character, and location of whatever insulation is used, and the method of bringing out the leads of the coil and connecting them to the commutator or the rest of the winding. The length of the piece of wire removed should be measured, and a new piece, a little longer than the old, cut for the new coil, of the same size wire and the same kind of insulation.

The new piece of wire should be carefully wound in place of the old coil, duplicating it in every feature, taking great pains not to kink the wire or bruise its insulation in the operation. It may be necessary for an inexperienced hand to make two or three trials before the coil is successfully rewound.

When complete, the binding wires should be replaced and the coil tested for grounds by the method illustrated in Art. **101**, before connecting it to the commutator. If free from grounds, it should be connected up, the heads on the armature replaced, and the armature put in its frame and tested for short circuits.

In replacing binding wires, they should be subjected to a considerable tension, so that when they expand as the armature heats up, they will not become loose. They should be soldered together quickly with a very hot iron, using again only resin as a flux.

109. Many makers balance their armatures by means of small masses of solder secured to the binding wires. If these binding wires are replaced, the armature must be

rebalanced in order that it may run without excessive vibration.

For this purpose, two iron or steel ways should be provided from $\frac{1}{8}$ to $\frac{3}{8}$ inch wide on the upper edge and 12 to 18 inches long, depending upon the weight and size of the armature to be balanced. These ways should be true and straight, set up level, and at such a distance apart that the journals of the armature shaft will rest upon them.

To balance the armature, it should be placed upon the ways, when it will turn over until the heavy side is beneath. A small weight (a piece of solder, for instance) should then be temporarily fixed to the upper part of the armature, which should then be just started in motion by the hand. It will then settle in some new position, when another weight should be temporarily placed on the armature, or a little of the other weight removed, according to the judgment of the workman. This operation should be continued until the armature shows no decided tendency to remain in any one position, when the weights may be permanently fastened in place.

The method of repairing broken leads, connections, and the like may be readily seen from the nature of the fault. In any kind of a repair, the object in view should be to replace the defective part, so that it will be exactly as it was before being damaged.

CONSTANT-CURRENT DYNAMOS.

110. All the preceding remarks concerning constant-potential dynamos (except those concerning shunt field coils) apply equally well to constant-current dynamos of the closed-coil armature type, and they should be installed and cared for in the same manner, and are subject to the same faults and injuries. In addition, whatever controlling apparatus is used should be kept in good working order and well oiled, especially when first started. The moving parts should not be allowed to get gummed up with oil and dust and should move freely without sticking.

Machines of the open-coil type, of which there are but few makes, usually require special precautions in setting the brushes, adjusting the controlling apparatus, etc., and their manufacturers supply pamphlets in which these and directions for otherwise adjusting and operating the machines are clearly set forth.

Open-coil machines, when running normally, always show a bluish spark from $\frac{1}{4}$ to $\frac{1}{2}$ inch long; but the commutators are so designed that this spark does no harm, and in fact is an indication that the machine is running properly. Any fault in the machine is usually indicated by some change in the character of the spark.

ALTERNATORS.

111. Alternators require no special directions for setting up, other than those given for constant-potential machines. The way in which the exciter (see Art. **29**) is to be set up will be evident from the construction of the machine.

Alternators should be given a trial run, without load, to make sure that the bearings are in good condition and to locate short circuits and open circuits in the windings. Short circuits manifest themselves just as they do in direct-current machinery, and may be similarly located (Art. **94**). If the armature is open-circuited, it will simply refuse to show any E. M. F. Some alternators have the armature divided into two parallel circuits, and an open circuit in one of these will not affect the E. M. F. at no load. When the load is put on, however, the open circuit will be indicated by excessive heating of the armature, excessive drop in the voltage, and generally by a fluctuation in the stray field similar to that produced by a short circuit.

An open circuit in the field winding may be easily detected, since the machines are separately excited. The exciter being a constant-potential direct-current machine, its faults or troubles may be detected as already described.

In setting the brushes, those on the collector rings require

no particular adjustment, except to see that they bear evenly and firmly on the surface of the rings.

The brushes on the commutator should be set opposite one another, and at such a point that the insulation between two segments is under a brush at the moment that the armature coils are in the position of least action (see Art. **29**). It should be remembered that in the *drum*-wound alternators, or those in which the coils are wound around teeth, the position of least action occurs when the coil or tooth is wholly under *one* pole-piece. See also Arts. **17** and **30**. When running under load, these brushes may need a slight adjustment forwards or back, as indicated by the sparking.

The operation of multiphase machines does not differ from that of ordinary alternators. On account of the simplicity of the winding and connections, alternators are, as a rule, less subject to electrical troubles than are direct-current machines; but as the voltage used is usually high, any accident which does occur is generally quite disastrous. For the same reason, cleanliness is a most important feature in the care of alternating-current machinery, and oil from the bearings must be rigidly excluded from the armature and field windings.

ALTERNATING-CURRENT MOTORS.

112. Synchronous motors are used only in the larger sizes, whose installation and preliminary operation are in the hands of experienced men who thoroughly understand the special features of starting and operating this class of machinery, and who make sure that these features are understood by the persons who are to have the machinery in charge. The rotary-field motors, however, are being installed in all sizes and places, but they require no special directions for operation, being usually even simpler than a direct-current motor.

The device for cutting out the starting resistance (see Art. **80**) should work freely and make good and firm

contact. If at any time the motor should become overloaded and stop, the current should be at once cut off and the machine turned over by hand with the load removed as far as possible, to see if the overload was due to excessive friction of the bearings; if this is the case, the trouble may be remedied as already described.

If found to be in the machinery the motor is driving, a part of the load should be removed and the machine started again.

If the current is left on the machine after it has stopped from overload, the field coils will become overheated and will eventually burn out.

ELECTRICAL MACHINERY IN GENERAL.

113. As before remarked, cleanliness is the essential feature in operating electrical machinery successfully, and care in this respect will usually prevent the development of serious trouble. Most of these troubles manifest themselves by excessive heating of one or more parts of the machine; so if at any time more than the normal amount of heating is noticed in any part of the machine, it should be at once examined, as already described, to discover the source and nature of the fault.

Noise is usually another indication that all is not working well, and all rattling, pounding, or squeaking should be investigated and the fault corrected, if possible. Carbon brushes which bear radially upon the commutator are the source of much noise, but with a glazed, smooth commutator and well-fitting brushes, this need not occur. A newly turned commutator will cause the brushes to "sing," as it is never exactly true, owing to the "jumping" of the tool in passing from segment to segment in turning it down.

To prevent unpleasant and even dangerous shocks, all electrical apparatus in operation should be handled with *one hand* only; that is, only one part of the machine should be touched at a time, and then only when the surrounding

floor and the shoes of the operator are dry or a dry piece of board is used to stand upon.

The shock of any circuit of less than 500 volts E. M. F. is not dangerous of itself to a person in good health, but may often cause one to lose his balance and fall upon or into moving machinery, and cause serious injury. The voltage of most alternators and the larger constant-current machines is high enough to give a fatal shock in most instances. If necessary to expose one's self to the liability of receiving such a shock, a pair of rubber gloves worn on the hands will afford protection; but even then care should be exercised in handling the wires or in touching "live" parts of the circuit.

NOTE.—In case a person has been exposed to a shock so violent as to cause insensibility, he should be treated as if drowned; that is, his breathing should be kept up artificially, by alternately pulling and releasing the tongue and raising and depressing the arms, with slow, rhythmical motions, until a physician can take charge of the case.

All permanent connections around a machine should be kept firmly fastened, as a loose connection will frequently be the cause of much more serious trouble. Whenever convenient, these connections should be soldered, and large wires and cables should be provided with brass or other metal tips or terminals, with which the necessary connection may be made.

It is not possible to lay down a set of rules by which all the troubles with dynamo-electric machinery that may occur may be located and obviated, but from those given, and from a knowledge of the principles under which these machines operate, most of the difficulties ordinarily met with may be overcome if *good judgment* and *common sense* are also used.

SWITCHBOARDS.

114. The switchboard is a necessary part of every plant. Its object is to group together at some one convenient and accessible point the necessary apparatus for controlling the dynamos and distributing the current to the various circuits, and the safety devices for properly protecting

the lines and machinery. The number and kind of these appliances depend upon the character and size of the plant.

There are four general types of switchboards in use, as follows:

1. Switchboards for arc-lighting circuits using constant currents.

2. Switchboards for incandescent-lighting circuits using direct currents at a constant potential.

3. Switchboards for incandescent-lighting circuits using alternating currents at a constant potential.

4. Switchboards for electric railroads using (ordinarily) direct currents at a constant potential.

Switchboards of all kinds are frequently made of wood, but this is not desirable on account of the danger from fire. The least dangerous type of wood switchboard is the skeleton type, which is merely an open framework of hardwood beams or joists, with its members so spaced as to properly support the instruments on the board. When properly built, this form of board is safer than any other wooden board, and in many places is the only type of wooden board allowed by the fire underwriters.

Switchboards of slate, marble, or soapstone are coming into more extensive use on account of their safety and appearance. These are made up in panels or slabs of convenient size, and from $\frac{3}{4}$ inch to 2 inches thick, according to circumstances. Being in themselves insulating material, the switches, etc., are usually mounted directly on the face of the board.

When all the wiring and connections are upon the face of the board, it may be mounted directly on the wall of the room; but if the wiring is all on the back of the board, as is the general custom, it should be placed at least 2 feet from any wall, so as to give a space for examining and making alterations in the wiring. A clear space of at least 2 feet should also be left between the bottom of the board and the floor.

SWITCHBOARDS FOR ARC-LIGHTING CIRCUITS.

115. This type of board is one of the simplest. Arc-lighting plants usually consist of several dynamos, of which any one must be capable of being switched into any one of several circuits. This may be accomplished in a variety of ways, but there are two in general use.

In the first method, the terminals of the various dynamos are led to a row of contacts on the bottom of the board. The terminals of the various circuits are led to a similar row (or rows) higher up on the board, and connection between the various members of the two rows is made with flexible insulated cables, provided with tips which are so arranged that the connection may be readily made.

To facilitate changing over from one circuit to another, the contacts are usually made double, so that two cables may

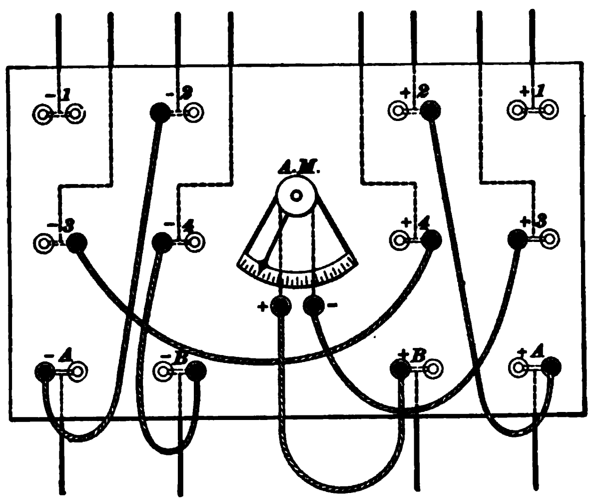


FIG. 48.

be connected to the same point if desired. The form of the contact varies with the different manufacturers, but is usually of the plug type; that is, the tip on the cable is in the form of a cylindrical brass plug, provided with a wooden or rubber handle, and the contact on the board is a short brass

tube into which the plug fits. This tube is generally split to insure firm contact, and often a spring latch is added to hold the plug in place when inserted.

Fig. 48 represents one form of this sort of board, arranged for two dynamos and four circuits. Each terminal is double, and those for the dynamos are arranged in the lower row, and marked $+A$, $-A$, $+B$, and $-B$, each dynamo being distinguished by its letter (A or B). The terminals of the four circuits are arranged in two rows at the top of the board, and are marked $+1$, -1, $+2$, -2, $+3$, -3, $+4$, and -4, each circuit being distinguished by its number (*1*, *2*, *3*, or *4*). The ammeter *A. M.* is mounted in the center of the board and provided with terminals (marked + and —) to enable it to be connected into any circuit, to determine if the current of that circuit is of normal strength. In this figure, the circuits are connected up as follows: Circuit *1* is "dead"; circuit *2* is on dynamo A, and circuits *3* and *4* are in series with each other, and are on dynamo B. The ammeter is also in this circuit.

116. The necessity for the two contacts at each terminal is obvious when it is considered that the external circuit of a constant-current dynamo should never be opened while the machine is running, because that would be equivalent to increasing the resistance of the external circuit, which would cause the E. M. F. to rise so suddenly as to endanger the insulation, besides making a long and vicious arc at the switchboard. It is often necessary to cut in or out circuits, machines, or the ammeter without stopping the plant, and, as stated above, without opening the circuit; with the two contacts at each terminal, and by the use of a sufficient number of connecting cables, these various changes in the connections may be easily made.

For example, suppose it is desired to connect the ammeter (in the foregoing figure) into No. *2* circuit. To disconnect it from circuits *3* and *4*, a cable is plugged in between the vacant contact at $+B$ and that at $+3$; this short-circuits the ammeter, which may then be disconnected from

terminals $+B$ and $+3$, and connected to terminals $+A$ and $+2$. Then, on removing the cable directly connecting $+A$ and $+2$, the ammeter is in No. *2* circuit.

Again, suppose it is desired to connect No. *1* circuit in series with No. *2*, without shutting down either the dynamo or No. *2* circuit. The first step would be to connect terminal $+1$ with terminal $+2$, then terminal $+A$ with terminal $+1$. These two make the same connection as the cable directly connecting terminal $+A$ and terminal $+2$, and this latter may be removed without affecting the circuits any. Terminals -1 and $+2$ are now connected together, and the connection between terminals $+1$ and $+2$ removed, throwing the two circuits (Nos. *1* and *2*) in series.

An examination of the board and a little practice in "plugging in" circuits when the dynamos are not running, will soon enable the operator to make any desired combination at will.

117. In the second method, the cables hanging across the front of the board are done away with, connection being made by means of plugs. This is accomplished by means of two groups of contacts, arranged in two parallel planes a little distance apart. The contacts in one group are divided into pairs of horizontal rows, each pair being connected to the terminals of one of the dynamos; the contacts of the other group are divided into pairs of vertical rows, each pair being connected to one of the circuits. The contacts are directly opposite each other, and the connection between any dynamo contact and any circuit contact is made by a long brass plug, which is pushed through the outside contact to the inside.

Fig. 49 is a diagram showing the connections of this form of board arranged for four dynamos and four circuits. The contacts in the front board are connected to the dynamo terminals, and those on the back board to the circuit terminals, as described above. It will be seen that owing to the way the connections are arranged, any dynamo may be connected to any circuit by simply pushing a plug (*P*, *P*, etc.)

through the contacts connected to the dynamo that correspond in position to those of the circuit it is desired to connect.

The back or *circuit* board is provided with an extra row of contacts at the bottom, by which circuits may be connected in series, using for the purpose cables with suitable terminals, similar to those used for connections in the first form of board described. One of these cables (called a *jumper*) is shown in the figure at *J*. In the diagram, circuit No. *4* is represented as being connected to dynamo *B*, and circuits Nos. *2* and *3* are in series and connected to dynamo *A*. Circuit No. *1* is "dead."

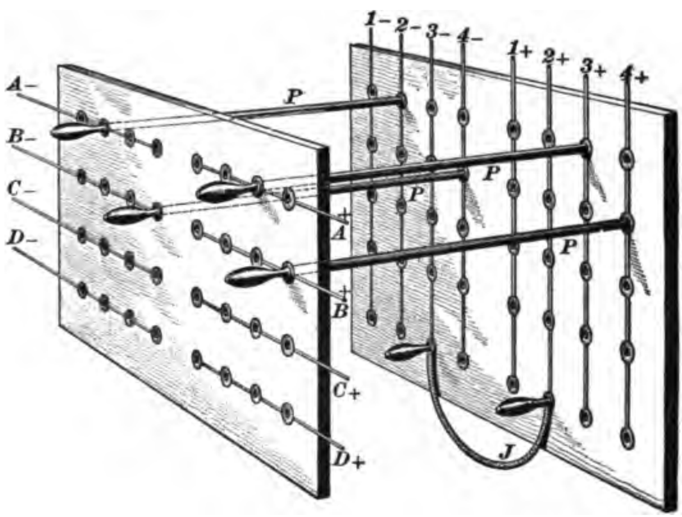


FIG. 49.

The method of connecting from one circuit to another, etc., will be evident from an inspection of the diagram, Fig. 49.

118. As constant-current dynamos are self-regulating, there is no liability of an excessive current flowing through any circuit, so that there is no need of safety devices to prevent the damage which such excessive current might do. The considerable length of overhead wire which is used for

arc-light circuits is exposed to the high potentials of lightning discharges, which are liable to puncture the insulation of the dynamo windings in the effort to get to the ground. To prevent this from occurring, apparatus called **lightning-arresters** are used.

The simplest form of lightning-arrester consists of a spark gap, or narrow space between the edges of two notched carbon or metal plates, one of which is connected to the line, the other to the ground. When the line becomes charged with atmospheric electricity (lightning) which is of the nature of static electricity, and therefore of very high potential, it is discharged by the lightning jumping across this narrow gap and passing into the earth. With this form of arrester, however, the dynamo current can follow the arc of the lightning discharge, and if the line happens to be grounded elsewhere, the current will flow through the circuit thus formed, which now presents a comparatively low resistance, and the arc will burn and destroy the arrester.

To prevent this, many forms of lightning-arresters have been constructed, in which the two plates between which the arc may form are suddenly moved apart whenever such an event takes place, thus rupturing the arc. Most of these are quite complicated, and are seldom sure to act; the *Thomson* arrester, however, performs the same office without moving parts, by taking advantage of the mutual reaction between a current and a magnetic field.

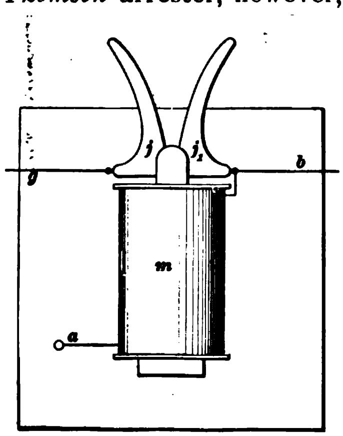


FIG. 50.

This arrester is illustrated in Fig. 50. The spark gap across which the lightning charge jumps exists between the two curved jaws j and j_1, jaw j being connected to the ground at g, and jaw j_1 being connected to the line at b. The gap between these jaws is not uniform in width; the

lightning discharge jumps across at the point where the jaws are nearest, and this point is situated between the poles of an electromagnet *m*, which is in series with the main or dynamo circuit, which is connected at *a*. Any current which passes across the gap between the jaws j and j_1 is therefore in the field of this magnet, whose polarity is so chosen that the reaction of the current on the field repels the current out towards the tips of the jaws, thus making its path so long that it can not follow it, and the arc is therefore "blown out," or ruptured.

119. The windings of the electromagnet serve another very important purpose. Without them, the lightning charge would have no particular preference for the spark gap of the arrester over the gap (insulation) between the winding and the frame of the dynamo, but as these magnets have considerable self-induction, the sudden rush of the lightning charge is prevented from passing through the magnet coils, and is therefore forced to pass across the spark gap in the arrester.

All good lightning-arresters should have a **choking coil,** as a coil is called which is inserted in a circuit merely for the effect of its self-induction or the obstruction it offers to rapidly changing currents. It should be remembered that the best arresters are useless unless their connection with the ground is carefully and thoroughly made and unless they are carefully installed.

The usual location for lightning-arresters is at the point where the circuits enter the station, one arrester being placed in each side of each circuit. A common ground-connection will do for the entire bank of connectors, if the number does not exceed ten. This ground-connection should be of two or three strands of No. 6 or No. 8 (B. & S. gauge) wire, run with as few bends and turns as possible to a thorough ground-connection, which should be either a large plate of copper buried in an excavation which has been carried down to *moist* earth and surrounded with coke or charcoal, or a piece of 1 or 1½ inch iron pipe at least

10 feet long, driven its full length into the ground, and provided with a brass plug in the top, to which the ground wire is attached. A supplementary connection may be made with a system of water-piping, if desired.

120. In using arc (constant-current) switchboards, it should be remembered that it is dangerous to break the circuit of a dynamo, while it is safe to short-circuit one: Breaking the circuit is liable, from the sudden rise in the potential, to puncture the insulation where it is weakest, on the line or in the machine, causing a ground. (See Art. **116.**)

Lines should be tested daily, when not in operation, for open circuits and grounds. A rough way of making such a test is by means of a magneto (Art. **32,** Part 2), which will show the presence of either an open circuit or a ground, but will not locate them from the station. Some manufacturers of arc-lighting apparatus furnish with their switchboards appliances for locating the position of a ground with considerable precision, which greatly facilitates its removal.

SWITCHBOARDS FOR DIRECT-CURRENT INCANDESCENT-LIGHTING CIRCUITS.

121. Incandescent lamps are usually operated in parallel, at a constant potential. When direct currents are used, the potential on a single circuit is seldom greater than 125 volts, and as each 16-candle-power lamp takes nearly .5 ampere at this voltage, the volume of current is considerable if a large number of lamps is operated. Consequently, the fittings, switches, and appliances on an incandescent-circuit switchboard are of more massive construction than those for arc-light circuits.

Direct current for incandescent lighting is distributed according to one of two general systems—the **two-wire** and the **three-wire systems.**

In the two-wire system, all the lamps are connected in parallel on a single circuit or set of circuits, there being but

two wires to each circuit, the wire which carries the current to the lamps being considered positive, and marked + in Fig. 51, and the wire carrying the current from the lamps back to the dynamo, which is called the negative, and is indicated by the sign —. The two-wire system is represented in Fig. 51, where *d* represents the dynamo which

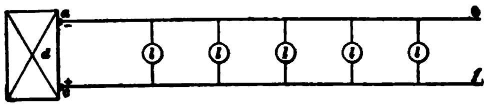


FIG. 51.

supplies the current to the lamps *l*, *l*, *l*, etc., by means of the two mains *a b* and *c f*. It will be seen that in this system each lamp or other device using the current is independent of the others, and may be turned off or on without affecting them. The current may be supplied from one dynamo or from several connected in parallel.

In the three-wire system, illustrated in Fig. 52, two dynamos *d* and d_1 are necessary.

These are connected in series, as represented, and a main *a b* led out from the — terminal of one machine, and another *c f* from the + terminal of the other machine. A third main *e h* is led out from the junction of the two machines, and it is between this main, called the *neutral* main, and either of the other two that the lamps or groups of lamps are connected in parallel, as shown.

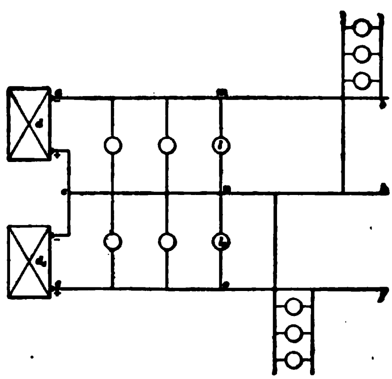


FIG. 52.

If the number of lamps connected between the neutral wire and either the + or the — main is the same, no current will flow from the dynamo through the neutral wire, since the current which flows through the lamps on one side is just that necessary for the lamps on the other, and it will

flow through them; but if a few more lamps are connected in on one side than on the other, then the *excess* of current required for the greater number of lamps over that required for the lesser will flow through the neutral wire.

If the lamps are so grouped that there will always be about the same number burning on each side of the neutral wire, only a small current will flow through it, and it may, therefore, be of much smaller wire than the + and − mains, although it is usually made the same size. The three-wire system requires at least two dynamos, although any number of pairs of machines may be used.

The exact arrangement of switchboards for incandescent-lighting circuits varies with the skill or judgment of the designer and the requirements of each case.

In general, however, the same apparatus is used in all boards, with about the same general arrangement, and a description of these general features will answer for almost all switchboards for either the two or three wire method of distribution.

122. Regulating Devices.—These consist chiefly of rheostats, or resistance-boxes, one being included in the shunt field circuit of each dynamo. The construction varies largely, the most usual, perhaps, being a box containing coils of German-silver or tinned-iron wire, which are connected at various points to contact segments, over which a traveling contact arm moves and cuts in or out the resistance as desired. (See Art. **51**, Part 1.) This arm may be operated by a knob or hand-wheel, suitably connected to the contact arm.

The rheostat is usually located on the lower part of the switchboard, so that the operating handle is about 3½ feet from the floor. It may be mounted wholly on the front of the board, but unless of extremely neat and compact appearance, it is usually better to mount it on the back of the board, the hand-wheel projecting through the board so it may be operated from the front. In some cases, the contact segments and contact arm are mounted directly on the front

of the board, connection to the resistance coils being made from the back.

It is usual to provide the resistance-box with an "open-circuit" point, so that after the contact arm has been so moved that all the resistance is in circuit, further movement breaks the circuit, thus shutting down the dynamo.

123. Switches.—Switches for incandescent work are usually of the *jack-knife* type, illustrated in Fig. 53. In this form of switch, the circuit is made or broken by means of a copper contact blade *k*, which fits between the flexible copper tongues of two contacts, as *c* and *d* or *a* and *b*. These are shown in perspective at *r*. Each contact blade is fitted to a lever l, l_1, pivoted at one end at p, p_1, and provided at the other with a handle *h* by which it may be operated. These

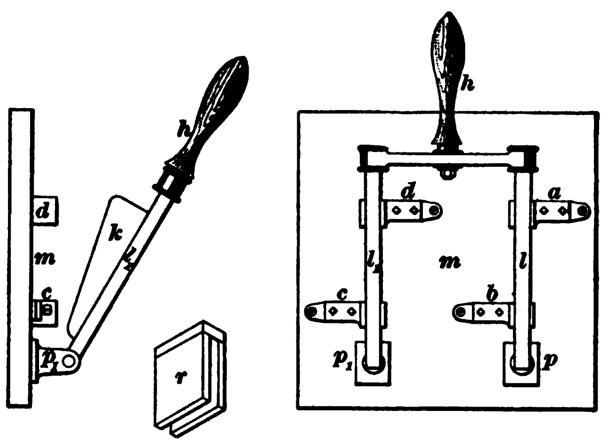


FIG. 53.

switches are provided with one, two, or three blades and sets of contacts, each insulated from the others, and are accordingly called single, double, or triple pole. These names are usually abbreviated to S. P., D. P., and T. P. Sometimes the levers are provided with two contact blades, one on each side, and a second set of contact points is placed on the other side of the pivot, so that by throwing the switch completely

over, that is, moving the handle through 180°, the contact points of this second set are connected together. Such a switch is called a double-throw switch; the switch illustrated in Fig. 53 is a double-pole, single-throw switch.

The contact points are provided with terminals of varying forms, to which the ends of the wires are connected. For use on wooden switchboards and for separate use, jack-knife switches are provided with a slate or marble base (*m*, Fig. 53), on which all the parts are mounted. On slate or marble switchboards, the various parts of the switch are mounted directly on the face of the board, connection with the contact pieces being usually made from the back of the board, so that no wires show in front. These switches should always be mounted on the board with the handle up, so that when opened they will have no tendency to close by their own weight.

124. Bus-Bars.—When several dynamos are to be run in parallel to supply a common set of circuits, it is customary to run a set of heavy wires or bars across the board, to which the dynamo terminals and the circuits may be attached at convenient points. These are called **bus-bars.** For three-wire systems, three bus-bars are necessary, and where two or more *compound-wound* dynamos are run in parallel, for a two-wire system, three bus-bars are also used, two being for the + and − terminals, the third being for the *equalizing connection*, the office of which will be explained later.

Bus-bars are usually made of bare copper rods, to facilitate making connection at any desired point, and are mounted either on the front or on the back of the board. When on the front, they are polished and add much to the appearance of the board. They are usually supported 2 or 3 inches from the face of the board by brass castings, whether on the front or back, and are made of large cross-section, so that the difference of potential between them is practically uniform at all points, even when large currents are flowing through them.

125. Instruments.—It is very desirable to know the output of each dynamo; consequently, an ammeter should be connected in circuit with each machine. The best forms of switchboard ammeters do not require that the whole current should enter the instrument, but instead only a small part, so that the ammeter may be located at any convenient point on the board, and the current carried to it by means of small wires. This is accomplished by making the ammeter of such resistance that when connected in parallel with a short length of the main conductor, or a specially prepared low resistance inserted in the main circuit, enough current will flow through the instrument to cause it to indicate, on a properly divided scale, the amount of the current flowing in the circuit to which it is connected. This often saves a great deal of wiring on a switchboard.

In incandescent-lighting plants, it is very necessary that the voltage of the circuits be maintained as nearly constant as possible, as variations of more than about 2% from the normal will affect either the life of the lamps or the quality of the light. For this reason, a reliable and sensitive voltmeter should be used to indicate the voltage of the various circuits. More than one instrument for the various circuits and dynamos is not necessary, for by the use of a small plug switchboard, which need be only a few inches square, or by the use of a specially devised switch, known as a **voltmeter switch,** a single instrument may be connected at pleasure with the terminals of any dynamo or any circuit, or may be used to indicate the presence of a ground in the dynamos or circuits, in the manner described in Art. **100.**

Switchboard instruments are, as a rule, made with large, open scales, so that they may be read at a distance. Voltmeters are often provided with a pointer, which may be moved by hand to the point where it is desired to keep the voltage constant; then, when the voltage is at the proper point, the voltmeter needle coincides in position with this pointer, which may be seen at a greater distance than the scale can be read.

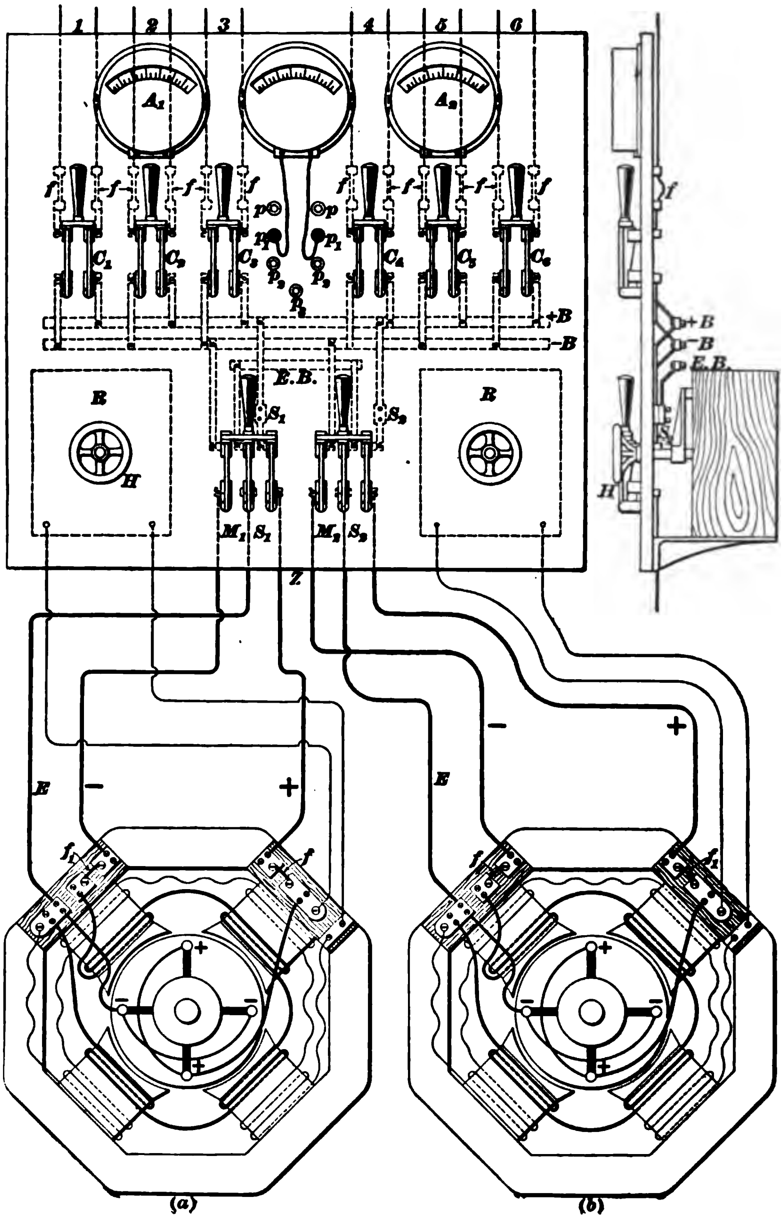


Fig. 54.

Incandescent lamps are often so arranged on the switchboard as to illuminate the scales of the instruments; if this is the case, the lamps should be shaded to prevent the light from shining in any other direction than directly on the face of the instrument, as otherwise they are practically useless.

126. Safety Devices.—To prevent the possible damage to dynamos and circuits, due to an excessive flow of current from any cause, fuses (see Art. **60**) are placed in each lighting circuit, also in each dynamo circuit. Those for the lighting circuits are usually placed at the top of the board, and form convenient points to which to attach the circuits. The dynamo fuses are sometimes placed at the bottom of the board, but more often on the connection board of the dynamo. The fuses should be of sufficient size to carry all the current that the various parts of the circuit in which they are connected will safely transmit.

The larger sizes of fuses are usually made in the form of strips, of rectangular section, mounted on copper terminals of suitable shape and size to clamp under the binding-screws of the fuse block.

The fuse blocks should be located on the back of the board, if possible, for if on the front, the board will be disfigured when the fuses "blow," unless they are completely enclosed.

Lightning-arresters similar to those described in connection with switchboards for arc-lighting circuits are also used for incandescent circuits, provided any part of the circuit runs out of doors for any distance. They are not usually installed on the switchboard itself, but at the point where the circuits leave the building.

127. Equalizing Connection.—When two compound-wound machines are connected in parallel by simply connecting the + terminals together and also the − terminals, each machine will furnish an equal share of the total current at all loads, providing their E. M. F.'s and their internal resistances are always exactly equal. This is seldom the case, however, especially as no two compound-wound

machines are overcompounded exactly alike. To enable them to be run in parallel satisfactorily, some device similar to the equalizing connection must be used. This is the simplest of the several methods, and the one most generally used, so the others need not be described.

Fig. 54 shows a switchboard embracing the features previously described, and showing the equalizing connection for running the two compound-wound dynamos in parallel. In this figure two 4-pole compound-wound dynamos (*a*) and (*b*) are represented. From the terminal boards of each machine three heavy leads E, $-$, and $+$ are carried to the triple-pole, single-throw switches $M_1 S_1$ and $M_2 S_2$. The $+$ lead is connected to the right-hand blade of the switch, the $-$ lead to the left-hand blade, and lead E to the central blade.

It will be seen that lead E is connected to the *armature* terminal on the side that the series coil is connected.

Now, suppose that both machines are running and that both switches $M_1 S_1$ and $M_2 S_2$ are closed. This connects the positive or $+$ lead of each machine to the bus-bar $+B$, the negative or $-$ lead of each machine to the bus-bar $-B$, and the E lead to the equalizing bus-bar $E B$. By tracing out these circuits, it will be seen that the current from the $-$ bus-bar has two paths open for it to reach the armature brush of either machine, one of which is through the $-$ lead and the series coils of that machine, and the other is through the series coils of the *other* machine and the two E leads.

If both machines are furnishing the same amount of current, there will be no current through the equalizing connection; consequently, the current from each machine will flow through its own series coils alone. If, however, through some change in the load, or from some other cause, the E. M. F. of one machine falls below that of the other, so that it (momentarily) furnishes less current, the drop through its series coils will be less than the drop through the series coils of the other machine, so that some of the current furnished by the other machine will flow through the equalizing connection and through the series coils of the first machine, thus bringing up the E. M. F. of this machine to its proper

value and causing it to furnish its share of the current. When the machines are first connected in parallel, their E. M. F.'s are adjusted by the field resistances until the load is equally distributed between them. When this has been done, the equalizing connection will take care of variations in the load.

128. Referring again to Fig. 54, R, R are the resistance-boxes which are included in the field circuits of the two machines, the connections being as indicated. These resistance-boxes are mounted on the back of the board, as indicated in the side view to the right, and the contact arm of each resistance-box which cuts in or out the resistance is operated by a shaft passing through the board and turned by a hand-wheel H.

The bus-bars are located on the back of the board, as indicated, and from them connection is also made on the back of the board to the lower terminals of the six double-pole, single-throw, circuit switches C_1, C_2, C_3, C_4, C_5, and C_6. Just above and connected to the upper terminals of these switches are a series of terminals for attaching the fuses f, f, f, etc., one of which is located in each side of the circuits *1*, *2*, *3*, *4*, *5*, and *6*. The main fuses f_1, f_1, etc., are located on the dynamo terminal boards.

Above the row of circuit switches are located the instruments, two ammeters A_1 and A_2, and a voltmeter V. The small leads from the ammeters (not indicated in the figure) are carried down the back of the board and connected to shunts S_1 and S_2, located in the connection between the + terminals of the switches M_1 S_1 and M_2 S_2 and the + bus-bar. The ammeters are connected in the + lead of the circuit, because all the current from one machine does not always pass through the — lead, on account of the equalizing connection. (See Art. **127.**) It will be seen that this method of connecting up the ammeters results in a great saving of connecting wire over the method which requires that the leads to the ammeter shall be of a size sufficient to carry the total current to be measured.

The voltmeter is provided with a pair of leads terminating in plugs, so that it may be connected to any of the plug contacts p, p, p_1, p_1, p_2, p_2, or p_3, as desired. These contacts are respectively connected by leads (not shown) on the back of the board, as follows: $p\,p$ to the lower (outside) terminals of switch $M_1\,S_1$, so that when the voltmeter is connected to these terminals, it measures the E. M. F. of machine No. 1, whether it is connected to the bus-bar or not; $p_1\,p_1$ to the similar contacts of switch $M_2\,S_2$; $p_2\,p_2$ to the bus-bars $+B$ and $-B$, and p_3 to the ground for the purpose of testing the insulation of the circuits or of the machines. (Art. **125.**)

If desired, lamps may be mounted on the board to illuminate the instruments, and in this case it would be well to supply two for each instrument, and connect one to each of the circuits *outside* the fuses, so that if any fuse should blow, the lamp connected to that circuit would indicate the fact by going out.

129. The foregoing figure and description show the general arrangement of switchboards for incandescent lighting with constant-potential dynamos. The exact arrangement for any particular case of course depends upon the circumstances of that case and the taste and judgment of the designer of the board, the principal object being to get, first, an economical and convenient arrangement of the necessary apparatus, and second, a neat and symmetrical appearance. In large plants employing a number of machines, it is more usual to use shunt-wound dynamos, the potential of which is kept constant by means of resistance-boxes in the field circuits operated by an attendant who has no other duty.

In isolated plants, such as those in theaters, office buildings, and the like, it is often desirable to run the plant on the two-wire system, but also desirable to have it arranged so that in case of accident to the plant, the lighting service can be continued from the mains of some central station, which are quite generally operated on the three-wire system.

To accomplish this, three bus-bars are used on the board, and each circuit has three wires, all lights being connected

between one or the other of the outer wires and the center one, which is made twice the size of the others. When run as a two-wire system, a large single-pole, single-throw switch connects the two outside bus-bars together as one, thus making the two outside wires of each circuit operate as one wire split into two parallel branches.

When it is desired to connect to the three-wire system, this single-pole switch is opened and the three bus-bars connected to the mains of the three-wire system in the regular way. This is known as the **flexible two-wire system,** and is very useful.

SWITCHBOARDS FOR ALTERNATING-CURRENT CIRCUITS.

130. Alternating currents are used largely for incandescent lighting in places where the lights are scattered over a considerable area. The current is generated and distributed at a high pressure (usually about 1,000 volts) to transformers (see Art. **40**) located at various points near where the lights are to be used.

This distribution being at a constant potential, the switchboard used is not much different in its essential features from that just described for direct currents. The exciter for each dynamo must be provided with switches and a field resistance-box on the board; an ammeter is also usually provided, to measure the field current of the alternator. For each alternator there are, therefore, two resistance-boxes (one in the exciter field circuit and one in the alternator field circuit) and two ammeters. When several circuits are operated, each circuit is usually provided with a switch, so that in such cases the alternating-current board has somewhat more apparatus than the corresponding direct-current board.

Alternators may be run in parallel, but first must be brought into synchronism (see Art. **69**). This involves a considerable amount of extra apparatus on the switchboard, and is liable to result in damage to the machinery if not properly done. For these reasons, alternators are seldom

run in parallel in this country, except in the large stations. If two or more machines are used, it is customary to divide the circuits into a suitable number of groups and run each group from one machine; provision is usually made, however, for throwing any group of circuits from one machine to another, generally by the use of double-throw switches.

On account of the above circumstances, the bus-bars used do not serve quite the same purpose in the alternating-current switchboard that they do in the direct-current, as they act only as connectors for the terminals of all the circuits comprising one group, there being, therefore, a pair of bus-bars for each group of circuits.

Instead of measuring directly the E. M. F. of the alternator, it is customary to use, in connection with the voltmeter, a small transformer, which has the same ratio of transformation as those used in the circuits. The secondary of this transformer is connected to the voltmeter, which, therefore, indicates the E. M. F. of the secondary circuits of the lighting system, 50 or 100 volts, or whatever it may be.

The alternating current at the potentials used on the primary circuits will give a dangerous, probably fatal, shock; the switchboard should therefore be carefully arranged so as to reduce the liability of accidental contact with any part of the primary circuit to a minimum. The high potential also increases the possibility of destructive arcs at the switch points and between the fuse terminals, when a loaded circuit is broken, so that the length of such breaks should be made great, to prevent as far as possible the occurrence of such arcs.

SWITCHBOARDS FOR ELECTRIC RAILROADS.

131. Electric-railroad systems, like incandescent-lighting systems, are operated with constant-potential circuits, usually of about 500 volts potential.

The general features of their switchboards are then similar to those for the lighting systems, some of the details, however, being necessarily somewhat different.

Compound-wound dynamos are generally used, being usually overcompounded from 8 to 12% or more. These are run in parallel, being connected through triple-pole main switches to three bus-bars, as in the lighting switchboard illustrated in Fig. 54.

The current is conveyed to the cars by means of an overhead line supplied by a number of feeders which go out from the station and connect with it at various points, the circuit being completed through the tracks and the ground. The feeders correspond to the various circuits in the lighting system, but are usually connected directly to the proper bus-bar, no switch or fuse being used. The part of the circuit connecting the station with the track or ground circuit is similarly connected to the other bus-bar, an ammeter being usually placed in this circuit to indicate the total output of all the dynamos.

In the circuit of each dynamo, between the main switch and one bus-bar, is connected the ammeter which measures the output of that dynamo, and also a **circuit-breaker,** which is an electromagnetic device for opening the circuit when the current exceeds a certain limit. This device takes the place of the fuses in the lighting system, and is used because it is much more rapid and certain in its action than a fuse. In case of a bad short circuit which causes an extremely heavy current to flow, the electromagnetic circuit-breaker operates almost instantaneously, while a fuse requires a certain length of time to heat up to the melting-point, which may be long enough to allow some damage to be done to the dynamos or engine by the overload.

The electric railroad being much more subject to short circuits and excessive currents than a lighting system, the use of fuses would require the expenditure of a great deal of time in replacing blown fuses, which is saved by the use of the circuit-breaker, since that requires only the movement of its handle to again make the circuit.

Lightning-arresters are provided in railroad as in other electric circuits, and are usually similar in character to those described. One arrester is connected in each feeder

circuit, and, as in the arc-lighting system, they are all connected to a common ground-connection. In addition to this ground-connection, the common connections of all the arresters may be connected to the track or ground bus-bar, but this latter connection should never be used as the only connection to the ground.

132. It will be seen from these remarks that, in general, the object of a switchboard is to enable each dynamo and each circuit to be treated as separate units, and, further, to admit of connecting up these various units in any combination that the business of the station may demand, with ease and rapidity and without danger to the machines, circuits, or operator. To accomplish this requires different apparatus and connections for different circumstances, and no general rule can be given for the arrangement of switchboards for even a particular system; but from the statements made, the manner in which the arrangement and apparatus of any particular switchboard serves its purpose should be readily understood after examining it and tracing out the connections.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS

TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been grouped into sections to which have been assigned the same section numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until the Instruction Paper having the same section number has been carefully studied.

STEAM ENGINES.

(PART 1.)

EXAMINATION QUESTIONS.

(500) (*a*) How may the work done by a moving piston be calculated? (*b*) If the cylinder volume is known, is it necessary to know its diameter or length in order to calculate the work done?

(501) A cylinder 32 inches in diameter has a volume of 24 cubic feet. The average net pressure on the piston is 21 pounds per square inch. (*a*) How much work does the piston do per stroke? (*b*) If the piston makes 60 strokes per minute, what horsepower is developed?

Ans. { (*a*) 72,576 ft.-lb.
(*b*) 131.96 H. P.

(502) In a pressure diagram, the mean ordinate is .57 inch long, and the length of the diagram is 2.9 inches. A vertical height of 1 inch represents 60 pounds per square inch steam pressure, and a horizontal distance of 1 inch represents 1.3 cubic feet. (*a*) What is the work done per stroke? (*b*) If the piston makes 74 strokes per minute, what is the H. P. developed?

Ans. { (*a*) 18,566.5 ft.-lb.
(*b*) 41.63 H. P.

(503) Show by a diagram why the expansive use of steam is economical.

(504) (*a*) How is the reciprocating motion of a piston changed into a continuous motion in one direction? (*b*) Describe the steam-engine mechanism by which this change is brought about.

(505) (*a*) Define the following: Head end and crank end of cylinder; forward stroke; return stroke; reciprocating parts. (*b*) When is an engine said to "*run right-handed?*" When does it "*run left-handed?*" (*c*) What is the stroke, and to what is it equal?

(506) What are the reciprocating parts? What is the duty of each?

(507) (*a*) Describe the action of the eccentric. What is (*b*) the throw of the eccentric? (*c*) The radius of the eccentric? (*d*) To what is the eccentric equivalent?

(508) (*a*) Why is the cylinder counterbored? (*b*) What are the duties of the following: Relief valves; stuffing-box and gland; piston rings; guides?

(509) What do you understand by the expression "an ordinary **D** slide valve?"

(510) What is (*a*) outside lap? (*b*) Inside lap? (*c*) Negative lap? (*d*) If a valve has neither lap nor lead, where does cut-off take place? (*e*) What would the angle between crank and eccentric be in the latter case?

(511) (*a*) What is lead? (*b*) What is the angle of advance? (*c*) If we increase the outside lap, how ought the angle of advance to be altered so as to keep the cut-off the same as before? (*d*) How is the angle of advance altered so as to give an increased lead?

(512) (*a*) What is the effect of changing the outside lap? (*b*) What is the effect of changing the inside lap? (*c*) What is the effect of changing the negative lap?

(513) What is meant by the terms "cut-off," "release," and "compression?"

(514) The travel of the valve is $3\frac{1}{2}$ inches. The lead is $\frac{1}{16}$ inch. The angle of advance is 30°. (*a*) Draw a diagram and determine therefrom the lap of the valve. (*b*) Find also the port opening when the valve is at the end of its travel.

Ans. $\begin{cases} (a) \ \frac{13}{16}''. \\ (b) \ \frac{15}{16}''. \end{cases}$

(515) In Question 514, suppose that the lead remains the same, but that the angle of advance is increased to 60°. (*a*) Determine from the diagram how much lap has been added to the valve. (*b*) What will be the port opening in this case?

Ans. $\begin{cases} (a) \ \frac{5}{8}''. \\ (b) \ \frac{5}{16}''. \end{cases}$

(516) (*a*) For what purpose is a rocker used between the eccentric-rod and valve rod? (*b*) What is the distinction between a direct and a reversing rocker? (*c*) What effect has a reversing rocker on the eccentric setting?

(517) A valve rod is attached to a direct rocker 28 inches from the pivot. The eccentric-rod is attached 20 inches from the pivot. The throw of the eccentric is 4 inches. What is the travel of the valve? Ans. 5.6 inches.

(518) What is the distinction between a direct and an indirect valve? Describe the action of the latter.

(519) In Fig. 6, the crank OA is shown on its inner dead center. The outer circle is the crank-pin circle; the inner circle is the one described by the center of the eccentric. Draw a diagram for each of the following cases, showing the setting of the eccentric. Take 30° as the angle of advance.

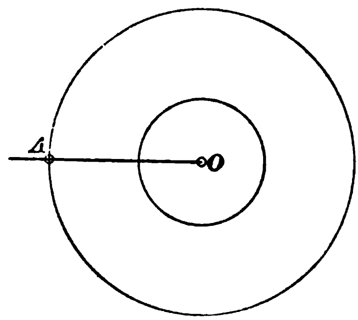


FIG. 6.

(*a*) Direct valve, direct rocker, engine runs over.
(*b*) Direct valve, direct rocker, engine runs under.
(*c*) Indirect valve, direct rocker, engine runs under.
(*d*) Indirect valve, direct rocker, engine runs over.
(*e*) Indirect valve, reversing rocker, engine runs over.
(*f*) Indirect valve, reversing rocker, engine runs under.
(*g*) Direct valve, reversing rocker, engine runs under.
(*h*) Direct valve, reversing rocker, engine runs over.

(520) What is the object of using the double-ported valve and the Allen valve?

(521) Describe the action of the Meyer cut-off valve.

(522) (*a*) What are the dead centers? (*b*) Can a single engine be started from a dead center? Give reasons for your answer.

(523) (*a*) How would you proceed to set a plain slide valve if link motion was used? (*b*) How would you set the valve if a Joy or See-Marshall valve-gear is used?

(524) (*a*) What is clearance? (*b*) How is it measured? (*c*) Why must an engine have clearance?

(525) (*a*) Define the following: Real cut-off; apparent cut-off; ratio of expansion. (*b*) If the clearance is 7% and the apparent cut-off $\frac{3}{8}$, find the real cut-off and the ratio of expansion.

Ans. (*b*) $\begin{cases} \text{Real cut-off, .416.} \\ \text{Ratio of expansion, 2.4.} \end{cases}$

(526) The piston of an 18″ × 40″ engine moves 9 inches before the steam is cut off. The clearance is 3%. What is (*a*) the apparent cut-off? (*b*) The real cut-off? (*c*) The ratio of expansion?

Ans. $\begin{cases} (a)\ .225. \\ (b)\ .2476. \\ (c)\ 4.04. \end{cases}$

(527) (*a*) If the average net pressure on the piston of the engine of Question 526 is 34.6 pounds per square inch, how much work is done per stroke? (*b*) Supposing the piston to make 140 strokes per minute, what is the H. P. developed?

Ans. $\begin{cases} (a)\ 29{,}348.87 \text{ ft.-lb.} \\ (b)\ 124.51 \text{ H. P.} \end{cases}$

(528) The steam enters the cylinder of the engine of Question 526 at a pressure of 100 pounds, absolute. (*a*) How many pounds of steam are used per stroke, assuming that no steam is saved by the early closure of the exhaust port? (*b*) Taking the horsepower as given in Question 527, how many pounds of steam are used per H. P. in one hour? Include clearance.

Ans. $\begin{cases} (a)\ .3459 \text{ lb.} \\ (b)\ 23\frac{1}{3} \text{ lb.} \end{cases}$

(529) Give a method of finding the area of an irregular figure by first finding its mean ordinate.

(530) What is the general rule for setting the eccentric (*a*) when both valve and rocker are direct? (*b*) When the valve is indirect and the rocker direct?

(531) What is the angle between crank and eccentric in the following cases, the angle of advance being 37°:

(*a*) Direct valve, reversing rocker?
(*b*) Direct valve, direct rocker?
(*c*) Indirect valve, direct rocker?
(*d*) Indirect valve, reversing rocker?

Ans. (*a*) 53°. (*b*) 127°. (*c*) 53°. (*d*) 127°.

(532) State and explain the different methods of propulsion of steam vessels.

(533) What is meant by (*a*) radial paddle-wheel? (*b*) Feathering paddle-wheel? (*c*) Slip? (*d*) Center of action? (*e*) Angle of incidence? (*f*) Rolling circle?

(534) A paddle-wheel steamer has a speed of 15 knots when the wheels make 40 revolutions per minute. If the effective diameter of the wheels is 14 feet, what is the percentage of slip? Ans. 13.57%, nearly.

(535) What is the diameter of the rolling circle of the wheels of the steamer mentioned in Question 534?

Ans. 12.1 ft., nearly.

(536) In what respect does a feathering paddle-wheel chiefly differ from a radial paddle-wheel?

(537) What do you understand by (*a*) radially expanded pitch? (*b*) Expanding pitch? (*c*) True screw?

(538) (*a*) How would you calculate the velocity with which a screw propeller projects a stream of water astern? (*b*) What is meant by the apparent slip of a screw propeller?

(539) (*a*) Explain how you would measure the pitch of a screw propeller. (*b*) How would you determine if the propeller is a true screw? (*c*) How would you determine if the propeller has a radially expanded pitch?

(540) Explain (*a*) thrust; (*b*) theoretical thrust; (*c*) actual thrust; (*d*) indicated thrust.

(541) An engine develops 1,020 I. H. P. when making 70 revolutions per minute. If the pitch of the screw propeller is 20 feet, what is the indicated thrust?

Ans. 24,042.86 lb.

(542) If the engine in Question 541 drives the vessel at a speed of 13 knots, what is the theoretical thrust, assuming the hub to be 4 feet in diameter and the propeller to be 18 feet in diameter? Take the weight of a cubic foot of sea-water at 64.1 pounds. Ans. 15,411 lb., nearly.

(543) A stern-wheel steamer, having engines developing 430 I. H. P. at 40 revolutions, has an effective diameter of the wheel of 18 feet. Find the indicated thrust.

Ans. 6,273.3 lb.

(544) A steamer 500 feet long has a displacement of 8,916.6 tons. If the coefficient of fineness is .5, what indicated horsepower will be required to drive the vessel at a speed of 17 knots? Ans. 8,802 I. H. P., nearly.

(545) If the engine is driven at 80 revolutions, and propels the vessel at the rate of 20 knots, how fast should the engine be run to give a speed of 18 knots?

Ans. 72 R. P. M.

(546) The engine of a screw-propeller steamer develops 8,000 I. H. P. at 80 revolutions. What power would it develop at 85 revolutions? Ans. 9,595.7 I. H. P.

(547) How will the lead be affected when the link is placed towards mid-gear (*a*) if open rods are used? (*b*) If crossed rods are used?

(548) What is the effect upon the steam distribution if the link is placed towards mid-gear?

(549) Are both steam ports opened the same distance with the See-Marshall gear?

(550) How is the cut-off changed with the Joy valve gear?

(551) Explain how you would place the crank of an inverted vertical engine on the dead center?

STEAM ENGINES.

(PART 2.)

EXAMINATION QUESTIONS.

(552) (*a*) What is meant by piston speed? (*b*) A 12″ × 12″ tugboat engine makes 120 revolutions per minute; what is its piston speed?

(553) (*a*) What is the mechanical efficiency of an engine? (*b*) How is it found?

(554) Define the following: (*a*) Net horsepower; (*b*) friction horsepower; (*c*) indicated horsepower.

(555) (*a*) What faults in steam distribution are shown

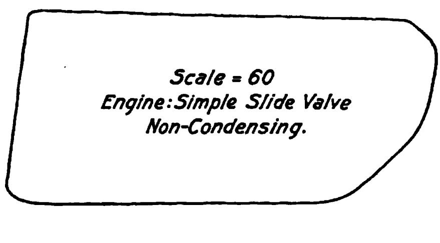


FIG. 7.

by the diagram in Fig. 7? (*b*) How may they be partially remedied?

(556) (*a*) How is the point of compression influenced by the speed of the engine? (*b*) What should be the amount of compression for high, slow, and medium-speed engines?

(557) (*a*) What may be inferred when the steam line falls abruptly? (*b*) When the back-pressure line is much higher than the atmospheric line, assuming the engine to be non-condensing? (*c*) When the actual expansion line rises far above the theoretical expansion line?

(558) (*a*) Describe the method of obtaining the steam consumption from the diagram. (*b*) Does the consumption so found represent the whole consumption? (*c*) Why? (*d*) What is the effect of cylinder condensation?

(559) (*a*) What is meant by absolute temperature? (*b*) What is meant by the thermal efficiency of a heat engine? (*c*) How may this efficiency be increased?

(560) A steam engine takes steam at 65 pounds, gauge pressure, and exhausts at 2.3 pounds above the atmosphere. What is the thermal efficiency of the engine? Ans. 11.94%.

(561) Describe briefly, in your own language, the surface condenser and jet condenser. (*b*) Explain the action of each. (*c*) Show why the addition of the condenser increases the economy of the engine.

(562) Can a condenser be run without an air pump and a vacuum be kept? Give your reasons, considering only the different condensers treated of in Arts. **1083** to **1097.**

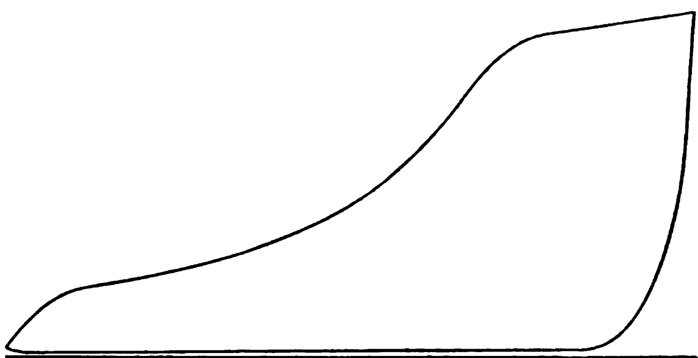


FIG. 8.

(563) Find the water consumption per I. H. P. per hour from the diagram, Fig. 8. Scale of spring is 40.

SUGGESTION.—Find the M. E. P. by dividing the diagram and measuring the ordinates, and then use rule **184.** The two points on the expansion and compression line called for in the rule may be taken at a distance of ¼ inch from the vacuum line.

Ans. 22.76 lb. per I. H. P. per hour.

(564) Give some of the causes of a poor vacuum.

(565) (*a*) What is an indicator diagram? (*b*) What are its three principal uses?

(566) The area of an indicator diagram is 3.47 square inches. One inch of length of diagram represents 6 inches of length of stroke; the scale of the spring is 40, and the diameter of the engine piston is 16 inches. (*a*) What is the work of the engine per stroke? (*b*) What is the horsepower of the engine if it makes 120 revolutions per minute?

Ans. { (*a*) 13,953.73 ft.-lb.
(*b*) 101.48 H. P.

(567) Explain fully the thermal advantages of the compound engine.

(568) (*a*) What is the I. H. P. of an engine, the M. E. P. being 47.1 pounds per square inch; the piston, 11 inches in diameter; the length of stroke, 18 inches, and revolutions per minute, 210? (*b*) If the mechanical efficiency of the engine is 83 per cent., what is the net horsepower? (*c*) The friction horsepower?

Ans. { (*a*) 85.45 H. P.
(*b*) 70.92 H. P.
(*c*) 14.53 H. P.

(569) (*a*) What is the thermal efficiency of a steam engine using steam at 60 pounds, gauge pressure, and exhausting at 2 pounds above the *atmosphere?* (*b*) If the pressure in the above case were raised to 90 pounds (gauge) and a condenser added giving a back pressure of 3 pounds above *vacuum* what would be the efficiency?

Ans. { (*a*) 11.55 %.
(*b*) 23.93 %.

(570) The stroke of a fore-and-aft compound engine is 30 inches; the diameter of the high-pressure cylinder is 19 inches and of the low-pressure cylinder, 32 inches; the M. E. P. of the former is 52 pounds per square inch and of the low-pressure cylinder, 18 pounds per square inch; the revolutions per minute are 120. (*a*) Find the I. H. P. of the engine. (*b*) What is the ratio of the work done in the H. P. cylinder to that done in the L. P. cylinder?

Ans. { (*a*) 531.27 H. P.
(*b*) 1.0184 : 1.

(571) (*a*) What defects in the distribution of steam may be shown by the indicator diagram? (*b*) What may be done to remedy the following faults:

1. Admission, release, and compression too early?
2. Admission, release, and compression too late?
3. Cut-off too early?
4. Cut-off too late?

(572) (*a*) Locate the points of cut-off, release, and compression in the diagrams, Fig. 9. (*b*) Assuming them to have been taken with a 30 spring, find the M. E. P. of each.

(573) In diagram *A*, Fig. 9, assuming a clearance of 6 per

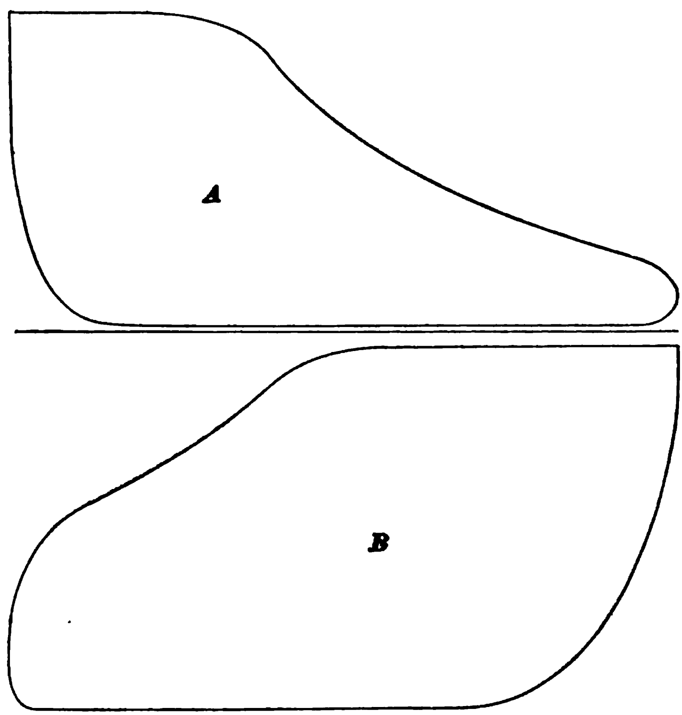


FIG. 9.

cent., draw the vacuum line, locate the point of cut-off, and draw the theoretical expansion line.

(574) The steam enters a jet condenser at a pressure of $4\frac{1}{2}$ pounds above vacuum; the condensing water enters at a temperature of 55°, and leaves, after mixing with the exhaust steam, at a temperature of 130°; what weight of condensing water must be used per pound of steam ?

Ans. 13.76 lb.

(575) The actual horsepower of an engine was found to be, approximately, 12.325. The I. H. P. from the diagram was 15.36. (*a*) Find the mechanical efficiency of the engine. (*b*) The engine had a $9'' \times 12''$ cylinder, and ran at an average speed of 240 revolutions; what was the M. E. P.?

Ans. $\begin{cases} (a) \ 80.24\%. \\ (b) \ 16.6 \text{ lb.} \end{cases}$

(576) What is the object of computing the steam consumption from both the point of cut-off and a point near release ?

(577) What should be the scale of the indicator spring used (*a*) if boiler pressure is 54 pounds ? (*b*) If the pressure is 115 pounds ? (*c*) The height of the steam line of a diagram, above the atmospheric line, is 1.834 inches; what is the gauge pressure of the steam at admission, if the diagram is taken with a 40 spring ?

(578) During an engine test, 906 pounds of exhaust steam passed through the surface condenser. The average pressure of the exhaust steam was 7 pounds above vacuum. The condensing water entered at an average temperature of 52° F. and left the condenser at an average temperature of 120° F. The average temperature of the condensed steam on leaving the condenser was 148.66°. How many pounds of water at a temperature of 52° were required ?

Ans. 13,580 lb.

(579) The diameters of the high-pressure, intermediate, and low-pressure cylinders of a triple-expansion engine are 27 inches, 42 inches, and 66 inches, respectively; the M. E. P.'s of the steam in the three cylinders are 72 pounds, 40 pounds, and 16.5 pounds, respectively; the stroke of the engine is 4 feet, and the number of revolutions per minute,

70. (*a*) Find the I. H. P. of the engine. (*b*) Find the percentage of the work done in each cylinder.

Ans. (*a*) 2,598 I. H. P.
(*b*) 26.9% in high-pressure cylinder.
36.2% in intermediate cylinder.
36.9% in low-pressure cylinder.

(580) Find, by means of rule **180**, the I. H. P. of an $18'' \times 24''$ engine whose mean effective pressure is 62.4 pounds per square inch, and which makes 175 revolutions per minute. Ans. 336.825 I. H. P.

(581) In Fig. 10 are shown the diagrams from both ends

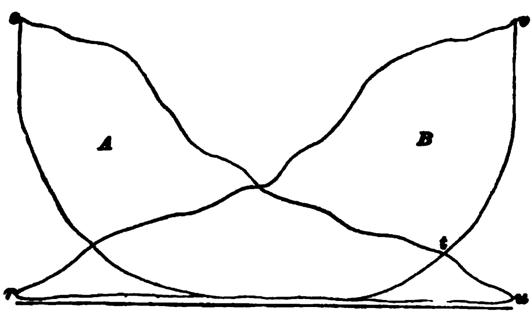


FIG. 10.

of the cylinder of a $13'' \times 12''$ engine running at 300 revolutions per minute; scale of spring, 60. Find the I. H. P. developed by the engine. Ans. 91.66 I. H. P.

(582) Find the water consumption per I. H. P. per hour from the diagrams shown in Fig. 10, Question 581.

Ans. 21.49 lb.

(583) The cylinder diameters of a triple-expansion engine are 30 inches, 44 inches, and 68 inches; the clearance in the high-pressure cylinder is 8 per cent., and the steam is cut off at $\frac{3}{8}$ stroke. (*a*) Find the ratio of expansion in high-pressure cylinder. (*b*) Find the total ratio of expansion. Ans. (*b*) 12.2.

(584) (*a*) What are the absolute temperatures corresponding to the following ordinary temperatures: 143°, 256°, 47.2°?

(*b*) What are the ordinary temperatures corresponding to the following absolute temperatures: 785°, 492°, 443°?

Ans. (*b*) $\begin{cases} 325°. \\ 32°. \\ 17° \text{ below zero.} \end{cases}$

(585) A plain slide valve is used in connection with a Stephenson link. As the link is hooked up, that is, as the link block is brought near the center of the link, the cut-off is diminished. (*a*) What is the effect upon the compression? (*b*) After starting an engine, the link is hooked up so that cut-off occurs successively at $\frac{5}{8}$, $\frac{1}{2}$, $\frac{3}{8}$, and $\frac{1}{4}$ stroke. Draw roughly the probable forms of the indicator diagrams at these points of cut-off. (*c*) Would the steam line be at the same height in all diagrams? Give reasons for your reply.

(586) A swinging lever 8 feet long is used for the reducing motion for an inverted vertical engine with 32 inches stroke. The diagram is to be $3\frac{1}{4}$ inches long. How far from the point of the lever should the indicator cord be attached? Ans. $9\frac{3}{4}$ in.

(587) Show, by means of an example taken from actual practice or one of your own invention, that if the result obtained by rule **169**, Art. **937**, be multiplied by the number of strokes per minute and divided by 33,000, the result will be the same as that obtained by rule **180**, Art. **1067**.

(588) The vacuum gauge on a condenser shows a vacuum of 23.9 inches. The temperature of the condensing water on entering is 52°, and on leaving, 105°. The temperature of the condensed steam on entering the air pump is 124°. The horsepower of the engine is 271.6, and it uses 27.8 pounds of steam per horsepower per hour. How many pounds of condensing water must be supplied per minute?

Ans. 2,452.6 lb.

(589) (*a*) Why is a pet-cock attached to an air pump? (*b*) Could an air pump be run without a foot-valve? (*c*) How should the air pump be placed in regard to the condenser?

(590) Describe briefly the Stevens' valve gear.

(591) Give the principle of operation of the Sickels' valve gear, and state in what respect it chiefly differs from the Stevens' valve gear.

(592) How would you prove the correct adjustment of the wipers in the Stevens' valve gear with respect to the rocker-arm ?

(593) (*a*) What is the use of the dashpot ? (*b*) Is there anything that may prevent the valves in the Sickels' valve gear from seating properly ?

(594) (*a*) What is the object of the bilge injection ? (*b*) How should it be fitted in regard to the main injection ?

(595) Describe a mud box, and state its purpose.

(596) Describe briefly the principle of operation of a pressure-reducing valve.

(597) Do you know of any instance when the power developed by one engine of a fore-and-aft compound or triple-expansion engine is purposely made larger than the power developed by the other engines ? If so, why is it done ?

(598) What is the purpose of the by-pass valve ?

(599) Explain how you would get a compound surface-condensing engine, having an independent circulating pump, ready for starting out. Explain, also, what precautions, if any, you would take before turning the engine over under steam.

(600) State some of the causes which may prevent the starting of an engine.

(601) How would you act in case one engine of a fore-and-aft compound was disabled ?

(602) How would you determine on which guide the pressure acts in the case of an inverted vertical engine driving a right-handed propeller ? A left-handed propeller ? Also state if the pressure will act on the same guide in both motions of the engine.

(603) Find the proper size of a single-acting plunger feed-pump for a 24", 46", and 67" × 48" condensing engine, with a surface condenser; boiler pressure is 170 pounds, absolute; apparent cut-off in high-pressure cylinder is at $\frac{5}{8}$ stroke; clearance, 8 per cent.; two feed-pumps are to be used; the stroke of the plunger is to be 24 inches.

Ans. $5\frac{1}{2}$ in., nearly.

(604) If the condenser in Question 603 was a jet condenser, what should be the diameter of the plunger, if the saturation were kept at $\frac{2}{32}$? Ans. $6\frac{5}{16}$ in., nearly.

(605) Describe briefly the principle of operation of (*a*) a single-connection lubricator · (*b*) a double-connection lubricator.

THE MACHINERY OF WESTERN RIVER STEAMBOATS.

EXAMINATION QUESTIONS.

(1) Will a stern-wheel engine run over or under when in the go-ahead motion?

(2) Explain the difference between a fixed cut-off and a variable cut-off engine.

(3) What are the functions of the full-stroke cam and cut-off cam employed on a fixed cut-off river engine?

(4) In an ordinary fixed cut-off river engine, how would you change from cutting off to full stroke?

(5) What is the purpose of and objection to ridering the exhaust-valve levers of the ordinary fixed cut-off river engine?

(6) With an ordinary fixed cut-off river engine employing one full-stroke cam, what will be the effect of giving lead to the steam valves when following full stroke?

(7) Why are the steam wipers of the Sweeney valve gear made different in shape from the exhaust wipers?

(8) In what respect does the California cut-off gear differ chiefly from the Rees cut-off gear?

(9) What do you understand by a pendulum motion?

(10) With a California cut-off, how would you lengthen the cut-off?

(11) With a Rees cut-off, how would you change from full stroke to cutting off and *vice versa?*

(12) How do you reverse a Rees cut-off engine?

(13) What do you understand by a two-valve engine?

(14) What influence has the size of a cam upon the opening and closing of the valves?

(15) Define the terms "throw" and "size" when applied to a cam.

(16) Is there any rule for calculating the throw of a cam?

(17) Given a sharp-pointed and a round-pointed full-stroke cam of equal size and throw. Which will be the quicker cam?

(18) Make a lead-pencil drawing of a cut-off cam designed to cut off at $\frac{9}{16}$ the stroke. The throw of the cam is to be 1 inch and the size 18 inches. Use a scale of 3 inches = 1 ft.

(19) Do you know of more than one method for laying out a full-stroke cam?

(20) For what point of cut-off would you design a cut-off cam intended to cut off at half stroke, when you know the cam is to be set to open the steam valves when the piston has completed 55 inches of the stroke? The stroke is 60 inches. Ans. $\frac{7}{12}$.

(21) Is it possible to have an equal cut-off on the forward and return stroke with the ordinary lever valve gear?

(22) Can the cut-off be made equal on a California cut-off engine? If so, why?

(23) How would you give exhaust lead to a California cut-off engine?

(24) What advantages, if any, has the Frisbie valve over the ordinary single-seated and double-seated poppet valve?

(25) Describe briefly the passage of the feed-water from the river to the boiler when a doctor is used.

(26) In what way does the open feed-water heater differ from the closed feed-water heater?

(27) Do you know of any device that will indicate a correct water level when the boiler is foaming?

RECENT DEVELOPMENTS IN MARINE ENGINEERING.

EXAMINATION QUESTIONS.

(1) What do you understand by (*a*) adiabatic expansion of a gas? (*b*) adiabatic compression? (*c*) isothermal expansion? (*d*) isothermal compression?

(2) Can expansion be adiabatic and isothermal at the same time?

(3) By what means may cold be produced?

(4) What is the ice-melting capacity of a refrigerating machine which abstracts 90,000 B. T. U. per hour?

Ans. 7.5 tons.

(5) The actual capacity of a refrigerating machine is 12 tons per day. If it takes 2,800 pounds of coal per day, what is the commercial efficiency of the machine?

Ans. 8.57 lb.

(6) In an air refrigerating machine is there any advantage of using air under pressure throughout the system?

(7) Define (*a*) aqua ammonia; (*b*) anhydrous ammonia.

(8) In what respects does the ammonia-compression system differ from the ammonia-absorption system?

(9) Explain in your own words the different refrigerating systems.

(10) What is the objection, if any, to using chloride of sodium for brine?

(11) Suppose that chloride-of-calcium brine commences to freeze; what would you do?

(12) In what respect does the can system of ice making differ from the plate system?

(13) Explain the circulation of the water in a Babcock-Wilcox boiler.

(14) Can you remove sulphate of lime from the feed-water by filtration?

(15) How can you tell if the water in the boiler is acid?

(16) Suppose you found the water acid; what remedy would you apply?

(17) A little ammonia and ammonium oxalate has been added to a sample of feed-water. Upon heating it, no matter precipitates. What conclusion would you draw?

(18) Is there any way in which the stream of feed-water entering a boiler can be made to improve the circulation?

(19) Explain the difference between a direct-connected and an indirect-connected steam steering engine.

(20) What precautions, if any, would you take before using and when using steam reversing gear?

DYNAMOS AND MOTORS.

(PART 1.)

EXAMINATION QUESTIONS.

(1) Fig. 1 represents a helix of wire around which an electric current is supposed to be circulating in the direction indicated by the arrows. Which of the two ends, *a* or *b*, is the north pole of the solenoid? Why?

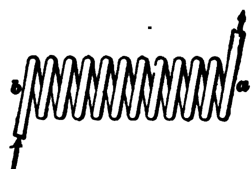


FIG. 1.

(2) (*a*) What will be the sign of the static charge developed on a glass rod when rubbed with fur? (*b*) on a piece of hard rubber when rubbed with silk? (*c*) on a piece of flannel when it is rubbed against a piece of amber? Give reasons.

(3) The electromotive force of a battery on open circuit is 20 volts and its internal resistance is 30 ohms. What will be the strength of current flowing when its poles are connected to an external resistance of 80 ohms?

Ans. .1818 ampere.

(4) The separate resistances of two branches *A* and *B* of a derived, or shunt, circuit are 16.2 and 14.1 ohms, respectively. If the sum of the currents in the two branches is 6.37 amperes, what is the current in each branch?

Ans. $\begin{cases} \text{2.9643 amperes in branch } A. \\ \text{3.4057 amperes in branch } B. \end{cases}$

(5) Express the equivalent of 2.33 horsepower in watts.

Ans. 1,738.18 watts.

(6) In a closed circuit, the resistance between two points is 2.3 ohms. (*a*) What current flowing between these points will cause a difference of potential of 58.4 volts? (*b*) What

is the power in watts dissipated between these two points? (*c*) Give its equivalent in horsepower.

Ans. { (*a*) 25.3913 amperes.
(*b*) 1482.8521 watts.
(*c*) 1.9877 horsepower.

(7) In a voltaic couple of zinc and platinum, which metal will be the negative element? Why?

(8) The current in a horizontal conductor is flowing from the north towards the south. In what direction will the north pole of a compass needle point if the compass is placed under the conductor?

(9) Fig. 2 represents a closed circuit consisting of a voltaic battery *B* and two conductors *X* and *Y* connected in series. The internal resistance of the battery is 17.2 ohms, and the separate resistances of the conductors *X* and *Y* are, respectively, 8.2 and 11.3 ohms. What is the total E. M. F. in volts generated by the battery if a current of .75 ampere flows through the circuit? Find the difference of potential in volts between *a* and *b*, between *b* and *c*, and between *c* and *a*.

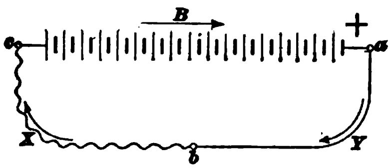


FIG. 2.

Ans. { Total E. M. F. developed by battery = 27.525 volts.
Difference of potential between *a* and *b* = 8.475 volts.
Difference of potential between *b* and *c* = 6.15 volts
Difference of potential between *c* and *a* = 14.625 volts

(10) If the specific resistance of silver is .5921 microhm per cubic inch, find the resistance in ohms of 1,000 feet of a round silver wire .2″ in diameter. Ans. .2262 ohm.

(11) A voltaic battery whose internal resistance is 36.2 ohms is connected to a copper wire having a resistance of 21.7 ohms. What is the total electromotive force in volts generated in the battery, if a current of .127 ampere flows through the circuit? Ans. 7.3533 volts.

(12) How many coulombs of electricity pass through a circuit in $2\frac{1}{4}$ hours when the strength of current is 8.32 amperes? Ans. 67,392 coulombs.

(13) Given, electromotive force = 112.5 volts and strength of current = 12.2 amperes; find the power in watts.

Ans. 1,372.5 watts.

(14) The separate resistances of two branches *A* and *B* of a derived, or shunt, circuit are, respectively, 2.4 and 987.3 ohms. What is their joint resistance in parallel?

Ans. 2.3941 ohms.

(15) The resistance of a copper wire is 43.2 ohms at 60° F.; find its resistance at 85° F. Ans. 45.5274 ohms.

(16) The separate resistances of three conductors *A*, *B*, and *C* are, respectively, 37, 45, and 72 ohms. What is their joint resistance when connected in parallel?

Ans. 15.8383 ohms.

(17) The total resistance of a closed circuit is 49.3 ohms. If the current flowing through the circuit is 2.73 amperes, what is the total E. M. F. in volts developed in the circuit?

Ans. 134.589 volts.

(18) The separate resistances of four conductors *A*, *B*, *C*, and *D* are, respectively, 3, 19, 72, and 111 ohms; find their joint resistance when connected in series. Ans. 205 ohms.

(19) (*a*) What is the total resistance of a closed circuit in which a current of 5.2 amperes is flowing and the total E. M. F. developed is 28.2 volts? (*b*) If the external resistance is 7 times the internal, what are the separate resistances of each?

Ans. { (*a*) The total resistance of the circuit = 5.423 ohms.
(*b*) The internal resistance = .677875 ohm, and the external resistance = 4.745125 ohms.

(20) How much energy in *joules* is expended in a closed circuit during $1\frac{1}{4}$ hours in which the current is maintained at 14.2 amperes, the resistance of the circuit being 8 ohms?

Ans. 7,259,040 joules.

(21) The resistance of a piece of silver wire is 214 ohms at 82° F.; find its resistance after its temperature has fallen to 50° F. Ans. 200.5608 ohms.

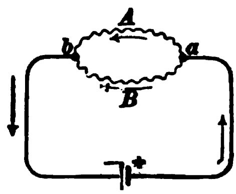


FIG. 3.

(22) In Fig. 3, the difference of potential between a and b is 11.6 volts. If the strength of the current in branch A is 6.7 amperes and the strength of the current in B is 4.9 amperes, what is the separate resistance of each branch?

Ans. $\begin{cases} \text{The separate resistance of branch } A = 1.7313 \text{ ohms.} \\ \text{The separate resistance of branch } B = 2.3673 \text{ ohms.} \end{cases}$

(23) The E. M. F. of a battery is 22.4 volts and its internal resistance is 13.4 ohms. What is the resistance of an external conductor connected to the battery when the current flowing in the circuit is .43 ampere?

Ans. 38.693 ohms.

(24) What must have been the strength of current in amperes in a closed circuit through which 368,422 coulombs of electricity passed in 4½ hours? Ans. 22.7421 amperes.

(25) Find the work done in foot-pounds when a current of 2.4 amperes flows against a resistance of 45 ohms for 50 minutes. Ans. 573,324.48 foot-pounds.

(26) Given, the electromotive force = 525 volts and strength of current = 12.5 amperes, express the number of horsepower. Ans. 8.7969 horsepower.

(27) (a) How many watts are dissipated by a current of 110 amperes flowing against a resistance of 4.2 ohms? (b) Give its equivalent in horsepower.

Ans. $\begin{cases} (a) \text{ 50,820 watts.} \\ (b) \text{ 68.1233 horsepower.} \end{cases}$

(28) The diagram in Fig. 4 represents a circular type of resistance-box with coils arranged for a Wheatstone bridge; X is an unknown resistance. Draw a diagram showing the proper connections of the battery and galvanometer circuits

and designate the upper and lower balance arms and the adjustable arm.

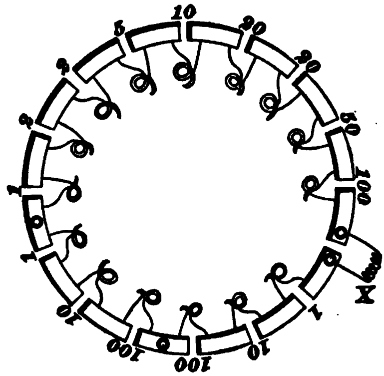


FIG. 4.

(29) If the resistance of 1,000 feet of round copper wire .1 in. in diameter is 1 ohm, find the resistance of 2,000 feet of square copper wire .1 in. on a side.

Ans. 1.5708 ohms.

(30) Find the equivalent of 54,200 watts in horsepower.

Ans. 72.6541 horsepower.

(31) The specific resistance of mercury is 37.15 microhms per cubic inch; find the resistance in ohms of a round column of mercury 72.3″ high and .04″ in diameter at 32° F.

Ans. 2.1368 ohms.

(32) The total E. M. F. developed within a battery is 45 volts and the internal resistance of the battery is 33 ohms; find the strength of current flowing when the battery is connected in circuit with a resistance of 30 ohms.

Ans. .7143 ampere.

(33) A voltmeter *V. M.*, Fig. 5, is connected to the poles *a* and *b* of a battery *B* whose circuit is open and indicates

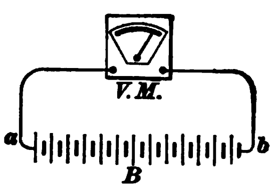


FIG. 5.

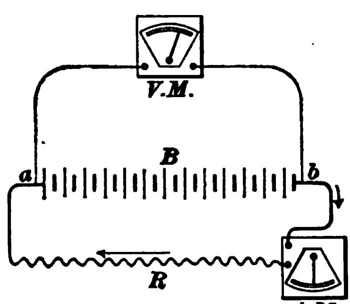


FIG. 6.

an E. M. F. of 24.4 volts. The battery is then connected in circuit with an ammeter *A. M.*, Fig. 6, and an unknown

resistance *R*. After these last connections are made, the voltmeter indicates an E. M. F. of 18 volts and the ammeter indicates a current of .8 ampere; determine the internal and external resistance of the circuit.

Ans. { Internal resistance = 8 ohms.
External resistance = 22.5 ohms.

(34) An E. M. F. of 510 volts is consumed in an electric receptive device and a current of 24.3 amperes is flowing in the circuit; calculate the power in watts supplied to the receptive device. Ans. 12,393 watts.

(35) A battery of twenty-four cells is arranged in multiple-series as shown in Fig. 7. There are four groups of six cells each, connected in series, and the four groups are connected in multiple, or parallel, to two main conductors c and c'. If the E. M. F. developed by each cell is 1.5 volts, what would be the E. M. F. indicated by the voltmeter *V. M.* when its binding-posts are connected to the main conductors c and c', as shown in the figure ?

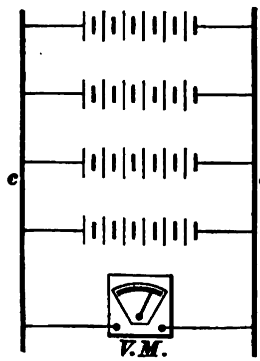


FIG. 7.

(36) The available E.M.F. developed by an electric source is 250 volts and a current of 65.7 amperes is flowing from it; determine its output in horsepower. Ans. 22.0174 horsepower.

(37) A conductor conveying a current of electricity is placed in a horizontal plane pointing north and south. If the north pole of a compass needle tends to point towards the east when the compass is placed directly under the conductor, in what direction is the current flowing in the conductor ?

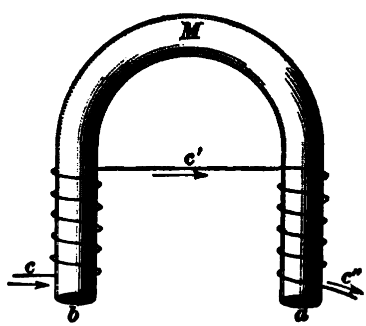


FIG. 8.

(38) Fig. 8 represents a horseshoe electromagnet *M*, around which is wound an insulated conductor *c c′ c″*. If a current circulates through the conductor in the direction as indicated by the arrows, which of the two ends, *a* or *b*, is the south pole of the magnet?

(39) A piece of ivory is rubbed with silk and a stick of sealing-wax is rubbed with fur; would the ivory and sealing-wax tend to attract or repel one another when brought near together, and why?

(40) The two voltaic elements in a cell are iron and graphite. Which of the exposed ends of the two elements forms the negative pole or electrode of the cell, and why?

(41) Give the names of all the known magnetic substances.

(42) A compass *C* is placed between the north and south poles of two magnets, as shown in Fig. 9. Towards which pole will the north pole of the compass needle tend to point, and why?

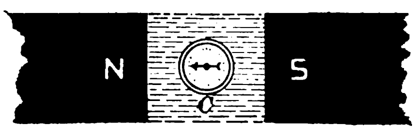


FIG. 9.

(43) A compass *C* is placed alongside of a bar magnet opposite the neutral line, as shown in Fig. 10. Towards which pole of the magnet will the south pole of the compass needle tend to point, and why?

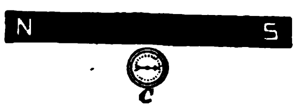


FIG. 10.

(44) A conductor conveying an electric current is placed in a horizontal plane pointing north and south, and the south pole of a compass needle tends to point towards the east when the compass is placed directly over the conductor. In which direction is the current flowing in the conductor? Give reasons.

(45) In an electromagnet, Fig. 11, the coil of wire is wound around an iron core in a right-handed spiral.

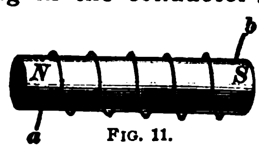


FIG. 11.

Through which end, *a* or *b*, of the wire must the current enter in order to produce the polarity as represented in the figure? Why?

(46) The resistance of a platinum wire 112 ft. 6 in. long is 100.8 ohms; calculate the resistance of 11.7 inches of the same wire, other conditions remaining unchanged.

Ans. .8736 ohm.

(47) If the resistance of a round iron wire 0.1″ in diameter is 86.5 ohms, calculate the resistance of a round iron wire .02″ in diameter, other conditions being equal in the two cases. Ans. 2,162.5 ohms.

(48) The resistance of a German-silver wire is 91.8 ohms at 45° F.; calculate its resistance when its temperature is 72° F., other conditions remaining unchanged.

Ans. 92.4048 ohms.

(49) If the resistance of a copper wire is .144 ohm at 87° F., what is its resistance at 41° F., other conditions remaining unchanged? Ans. .131 ohm.

(50) If the specific resistance of platinum is 3.565 microhms per cubic inch, find the resistance in ohms of a round platinum wire 126 ft. long and .1 in. in diameter.

Ans. .686 ohm.

(51) The diagram, Fig. 12, represents a particular pattern of resistance-box for a Wheatstone bridge, with battery and galvanometer circuits properly connected for taking resistance measurements. An unknown resistance X is connected to the terminals *c* and *b*. After adjusting the resistances of the same by withdrawing the plugs, as represented by the open spaces between the contacts, the galvanometer shows no deflection when the keys *k* and *k′* are pressed and the battery and galvanometer circuits are closed. Under these conditions, what is the resistance of X?

Ans. 7.23 ohms.

(52) The total E. M. F. developed in a closed circuit is 36 volts; the internal resistance is 18 ohms and the external resistance is 24 ohms; determine the strength of current in amperes flowing in the circuit. Ans. .8571 ampere.

(53) A current of 2.7 amperes is flowing in a closed circuit. If the total E. M. F. developed in the circuit is 12.6 volts, what is the total resistance of the circuit?

Ans. 4.6667 ohms.

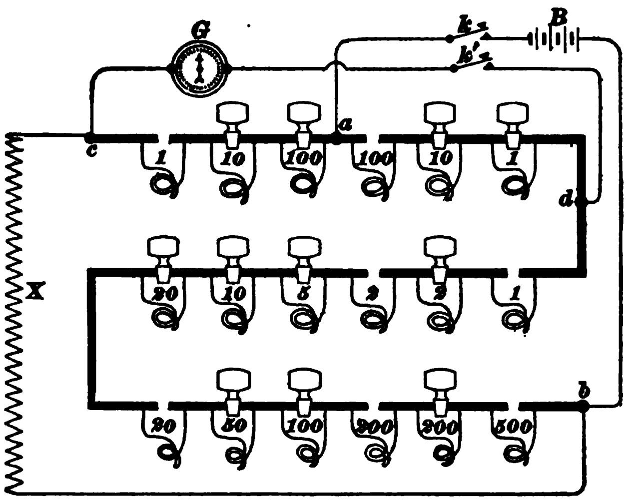


FIG. 12.

(54) The external resistance of a closed circuit is 31.5 ohms and the internal is 11 ohms. If a current of .8 ampere is flowing through the circuit, what is the total E. M. F. in volts developed? Ans. 34 volts.

(55) A German-silver wire offers a resistance of 204 ohms. What would be the difference in potential in volts between its two extremities if a current of .12 ampere flowed through it? Ans. 24.48 volts.

(56) The total E. M. F. developed in an electric source is 250 volts. If 10% of this E. M. F. is required to transmit a current of 80 amperes to and from a receptive device situated 600 feet from the source, (*a*) what is the total resistance of the two conductors, and (*b*) what is their resistance per foot, considering each to be 600 feet long?

Ans. { (*a*) .3125 ohm.
(*b*) .00026 ohm per foot.

(57) The internal resistance of a battery is 8.1 ohms and the total E. M. F. developed in it is 24 volts. What is the available or external E. M. F. of the battery when the circuit is completed by an external conductor offering a resistance of 15.9 ohms? Ans. 15.9 volts.

(58) The separate resistances of two branches *A* and *B* of a derived circuit are 1.2 and 2.2 ohms, respectively. If the sum of the currents in the two branches is 45 amperes, what is the current in each branch?

Ans. { The current in branch *A* is 29.1176 amperes.
The current in branch *B* is 15.8824 amperes.

(59) The separate resistances of two conductors are, respectively, 45 and 63 ohms; determine their joint resistance when connected in parallel or multiple.

Ans. 26.25 ohms.

(60) The separate resistances of three conductors *A*, *B*, and *C* are 414, 810, and 1,206 ohms, respectively; determine their joint resistance when connected in parallel or in multiple. Ans. 223.2534 ohms

DYNAMOS AND MOTORS.

(PART 2.)

EXAMINATION QUESTIONS.

(1) Suppose that a ring-core armature of a bipolar dynamo is wound with 200 complete turns of wire which are properly connected to the segments of a commutator for generating a continuous current, and that there are 6,250,000 lines of force passing through the armature from the poles of the field-magnets. If the strength of the field remains constant and the armature is rotated at a uniform speed of 1,200 revolutions per minute, what is the total electromotive force in volts generated in the armature?

Ans. 250 volts.

(2) If the resistance of the field coils in a shunt dynamo is 440 ohms, and the difference of potential between the brushes when the external circuit is open is 220 volts, what is the strength of current in the field coils? Ans. .5 ampere.

(3) What is the distinction between an alternating current and a continuous current?

(4) Fig. 1 shows a cross-sectional view of a uniform magnetic field taken at right angles to the direction of the lines of force; that is, the dots represent the ends of the lines of force, their direction being downwards, piercing the paper. *C* represents a closed coil of some conducting material, such as copper, that is placed in the magnetic field with its plane at right angles to the direction of the lines of force. If the closed coil is

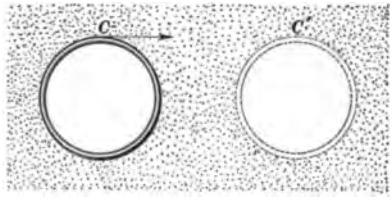


FIG. 1.

suddenly moved from its original position to another position in the field, as to C', as shown by the dotted coil, without changing the relative position of its plane with the direction of the lines of force, state whether or not a momentary current will circulate around the coil when the movement is made, and give the reason.

(5) The efficiency of a dynamo at full load is 88%, and at this load it requires an input of 18 horsepower to drive its armature. Determine the output in watts under these conditions. Ans. 11,816.64 watts.

(6) The output from a certain dynamo is 17,500 watts, and its efficiency at this output is 87.5%. If 2.6% of the input is used to excite the field-magnets, state the field loss in watts. Ans. 520 watts.

(7) The resistance of the shunt-field coils of a constant-potential dynamo is 55 ohms, and the difference of potential between the brushes when the armature is revolving at normal speed is 110 volts. How many watts are required to excite the field magnets? Ans. 220 watts.

(8) What is a commutator and for what is it used?

(9) A field rheostat is connected in series with the field circuit of a constant-potential shunt dynamo. When the external circuit of the dynamo is open, all the resistance of the rheostat is in circuit with the field coils and a current of 1.5 amperes is flowing through the field circuit. After the external circuit is closed and the current from the armature increases, it is necessary to cut out or short-circuit the resistance of the rheostat in order to keep the difference of potential between the brushes at 360 volts from no load to full load. At full load, the current in the field is 1.8 amperes; find the amount of resistance which was cut out or short-circuited in the rheostat. Ans. 40 ohms.

(10) The output of a dynamo is 65,000 watts, and its efficiency at this output is 90.5%; determine the input to the armature, and express the same in horsepower.

Ans. 96.2777 horsepower.

(11) Fig. 2 shows the connections of a shunt dynamo and the direction in which the field coils are wound. If the current flows in the direction indicated by the small arrow-heads, which of the two pole-pieces, *P* or *P'*, is the north pole? Suppose that the winding of the right-hand coil were reversed, which pole-piece would then be the north pole?

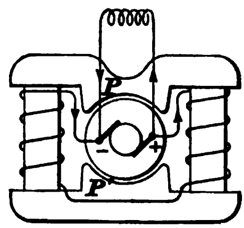


Fig. 2.

(12) Define a ring winding and a drum winding, and point out the difference between the two.

(13) The input to a dynamo is 10 horsepower and its output is 6,341 watts. What is its efficiency at this load?

Ans. 85%.

(14) Fig. 3 represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of the

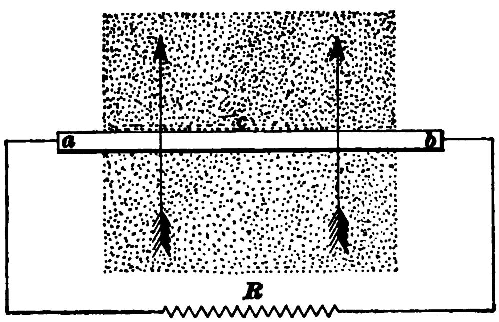


Fig. 3.

lines of force, their direction being downwards, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south pole; *c* represents a moving conductor placed in the magnetic field with its length at right angles to the direction of the lines of force; its two ends are connected to an external circuit consisting of the resistance *R*. If the conductor is moving upwards across the magnetic field in the direction as shown by the large arrows, in which direction will the current tend to flow in the circuit?

(15) A dynamo shows an efficiency of 85% when its output is 11,900 watts, and 1.8% of the input is lost in the core by eddy currents and hysteresis. What is the core loss in watts? Ans. 252 watts.

(16) (*a*) What is meant by the *counter torque* of a dynamo? (*b*) What causes it?

(17) A dynamo generates 125 volts at a normal load of 120 amperes output. If the resistance of the armature from brush to brush is .040 ohm, what is the armature loss in watts due to resistance? Ans. 576 watts.

(18) In example 17, if the efficiency of the dynamo at the normal output is 75%, what per cent. of the input is lost in the armature, due to its resistance? Ans. 2.88%.

(19) (*a*) What is meant by the *sparking limit* of the load of a dynamo? (*b*) What causes the sparking?

(20) In a compound-wound dynamo the resistance of the shunt-field coils is 550 ohms, and the resistance of the series-field coils through which all the current to the external circuit flows is .04 ohm. The dynamo generates 550 volts between its brushes when the output is 40 amperes. Determine the total number of watts lost in the shunt and series field coils combined at this output. Ans. 614 watts.

(21) Fig. 4 represents the field-magnets of a bipolar dynamo with consequent poles. If the field-magnets are separately excited by the battery B, which is connected to the four field coils a, b, c, and d, and the coils are connected together in series as shown in the diagram, which of the two consequent poles, P or P', will be the south pole of the field-magnet?

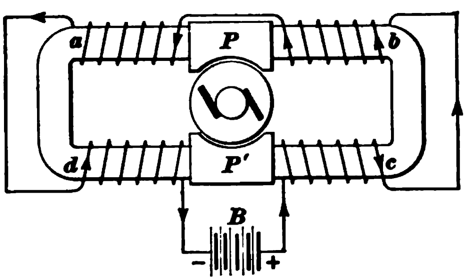


FIG. 4.

(22) What causes the neutral points in a dynamo to shift when a current is flowing in armature conductors?

(23) The separate losses at full load in a particular dynamo are as follows:

Loss in mechanical friction = 356 watts.
Loss in eddy currents and hysteresis = 178 watts.
Loss in field coils = 263 watts.
Loss in armature ($C^2 r$) = 423 watts.
All other losses = 50 watts.

If the output of the dynamo at full load is 15,000 watts, determine its per cent. efficiency. Ans. 92.1942%.

(24) (*a*) In example 23, what per cent. of the input is lost in mechanical friction? (*b*) in eddy currents and hysteresis? (*c*) in the field coils? (*d*) in the armature wires? (*e*) What is the total per cent. loss in the dynamo?

Ans. {
(*a*) 2.1881% loss.
(*b*) 1.094% loss.
(*c*) 1.6165% loss.
(*d*) 2.5999% loss.
(*e*) 7.8058% total loss.

(25) If a certain dynamo generates 440 volts when driven at a speed of 1,200 revolutions per minute, what electromotive force will it generate when driven at 1,400 revolutions per minute, all other conditions in regard to strength of field, armature reactions, and number of armature conductors remaining unchanged? Ans. $513\frac{1}{3}$ volts.

(26) What limits the output of a constant-potential dynamo? Why?

(27) In Fig. 5, C represents an iron-magnet core around which the two coils P and S are wound. The coil P acts as a primary coil and is connected to the terminals m and n of a voltaic battery B. The coil S is, therefore, a secondary coil and its two ends are connected to the terminals x and y of an external resistance R. A key k is inserted into the primary circuit

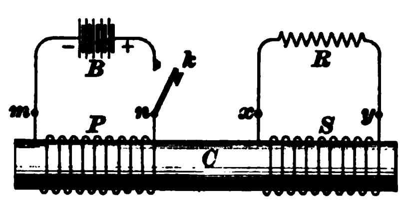


FIG. 5.

for opening and closing the circuit at will. If the negative electrode of the battery is connected to the terminal *m* in the primary circuit and the circuit is suddenly closed at *k*, in what direction will the momentary current induced in the secondary coil *S* flow ?

(28) In example 27, suppose that the circuit of the primary coil *P* was closed until the current in the circuit had become perfectly steady and then suddenly opened at *k*. In what direction would the momentary current induced in the secondary coil *S* flow ?

(29) Give two reasons why carbon brushes will spark less than copper brushes, under the same conditions.

(30) Fig. 6 represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of the lines of force, their direction being downwards, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south pole.

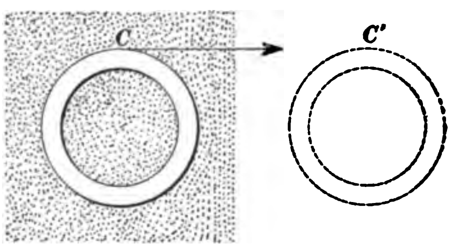


FIG. 6.

The ring *C* is a closed coil of some conducting material, as copper, and is placed in the magnetic field with its plane at right angles to the direction of the lines of force. Imagine the coil to be suddenly jerked from its position to one outside the magnetic field, as, for instance, to *C'*, assuming, of course, that its plane is kept always at right angles to the direction of the lines of force. Will a momentary current be produced in the closed coil, and if so, in which direction will it circulate around the ring ?

(31) What is a compound-wound dynamo, and why are dynamos compound-wound ?

(32) If a conductor cuts 8,000,000 lines of force in one-quarter of a second, what is the *rate of cutting* per second ?

(33) State why a solid piece of iron will not answer for a revolving armature core.

(34) Suppose that a drum-core armature is wound with 150 complete turns of wire which are properly connected to the segments of a commutator for generating a continuous current, and the armature is placed in the field-magnets of a bipolar dynamo. If there are 2,500,000 lines of force passing through the armature and the armature is rotated at a uniform speed of 1,020 revolutions per minute, what is the difference of potential in volts between the brushes in open circuit? Ans. 127.5 volts.

(35) In a particular dynamo, if an electromotive force of 200 volts is generated when there are 750,000 lines of force passing through the armature, what electromotive force would be generated if the strength of the field were increased so that 1,250,000 lines of force passed through the armature, assuming that all other conditions as to speed, number of conductors, armature reactions, etc., remain unchanged? Ans. $333\frac{1}{3}$ volts.

(36) To what are the following losses in a dynamo due: (*a*) core loss? (*b*) armature loss? (*c*) field loss?

(37) In Fig. 7, the observer is looking at the face of a north magnetic pole *N*, and a straight conductor *C* is placed in a vertical position in front of the pole with its length at right angles to the direction of the lines of force as they pass out from the pole. If the two ends of the conductor are connected to the terminals of the battery *B*, and a current flows through the circuit thus formed in the direction indicated by the arrow-heads, towards which side, *a* or *b*, of the pole face will the conductor tend to move?

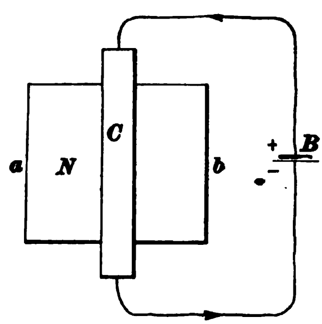


FIG. 7.

(38) In a shunt dynamo, if the resistance of the field coil is 650 ohms and the difference of potential between the brushes remains constant at 525 volts when the armature is rotated at a constant speed, what is the strength of current in the field coil under these conditions? Ans. .8076 ampere.

(39) A compound dynamo generates 115 volts between its terminals when no current is flowing into the external circuit. At full load, however, the difference of potential between its terminals is 124.2 volts. What per cent. over-compounding do these figures represent? Ans. 8%.

(40) Define an open-coil winding and a closed-coil winding, and point out the difference between the two.

(41) If it requires 44 horsepower to drive the armature of a dynamo when it is delivering 29,820 watts, what is the efficiency of the dynamo under these conditions?

Ans. 90.8481% efficiency.

(42) Find the total per cent. of the input lost in a dynamo when it is delivering 17,500 watts, if it requires 20,000 watts to drive its armature shaft at this output.

Ans. 12.5% total loss.

(43) The efficiency of a dynamo at its rated output of 12,500 watts is 92.5%. Determine the number of horsepower input necessary to give this output.

Ans. 18.1146 horsepower.

(44) What becomes of the heat generated in a dynamo armature?

(45) If 55 horsepower is the input to a dynamo and its efficiency at this input is 88.5%, find its output in watts under these conditions. Ans. 36,311.55 watts.

(46) The input to a generator is 45 horsepower, and 2% of this input is lost in exciting the field coils. State the field loss in watts. Ans. 671.4 watts.

(47) State the differences of separately-excited, shunt, and series-wound dynamos.

(48) The core losses in a particular generator amount to 800 watts and the input to the generator is 64 horsepower at full load. Determine the per cent. loss in the core at this input. Ans. 1.6756%.

(49) Why must the brushes of the dynamo be shifted ahead of the neutral point when operating under load?

(50) What is the difference between a consequent pole and a salient pole?

DYNAMOS AND MOTORS.

(PART 3.)

EXAMINATION QUESTIONS.

(1) (*a*) What is a transformer? (*b*) For what purpose is a transformer used?

(2) What is the relation between the counter E. M. F., the applied E. M. F., and the drop or fall of potential, in a direct-current motor armature?

(3) How can a short-circuited coil in an armature winding be detected?

(4) Which form (ring or drum) of armature winding is most generally used for alternators?

(5) Why will an ordinary series-wound dynamo, without regulating devices, not give a constant current through a circuit of varying resistance?

(6) What causes the current in an alternating-current circuit to lag behind the E. M. F.?

(7) What is meant when two alternating currents are said to differ in phase?

(8) Suppose that a direct-current motor when running shows a flash at each brush once in each revolution, and on examination it is found that one of the commutator segments is blackened and burned quite badly. What is the trouble?

(9) What causes an ordinary series-wound motor to race or run away (*a*) when connected in a constant-current circuit? (*b*) when connected to a constant-potential circuit and all the load removed?

(10) (*a*) What is meant by a *cycle* in speaking of an alternating current? (*b*) What is meant by the *frequency* of an alternating current?

(11) How is the Thomson-Houston constant-current dynamo regulated to give a constant current?

(12) What is the *effective* strength of an alternating current?

(13) A certain series-wound motor is tested with a Prony brake, the distance from the center of the shaft to the point where the arm of the brake rests on the scale platform being 36 inches. The brake is tightened until the pressure on the platform is 27 lb., when the following readings are taken: Current to motor, 25 amperes; volts at terminals, 480; speed, 900 R. P. M. (*a*) What is the output of the motor in H. P.? (*b*) What is its efficiency at this output?

Ans. $\begin{cases} (a) \text{ 13.88 H. P.} \\ (b) \text{ 86.3\%.} \end{cases}$

(14) Why will an alternator armature not start to turn if supplied with an alternating current from some external source, the fields being excited?

(15) In a bipolar shunt motor with two field coils, one of the field coils becomes short-circuited. (*a*) What is liable to happen to the other coil? (*b*) Why?

(16) Draw a diagram showing the connections of a shunt-wound motor with main switch, reversing-switch, starting resistance, and fuse boxes.

(17) How may the speed of a direct-current motor be varied?

(18) Why is the resistance of a circuit having self-induction apparently greater with alternating currents than with continuous?

(19) When two coils or sets of coils in an open-coil constant-current armature are connected in parallel by the brushes, and the E. M. F. in one coil is less than that in the other, why does not a current flow from the coil having the higher E. M. F. around through the other?

(20) What operations would be gone through with in cutting out circuit No. *4* and plugging in circuit No. *1* in

series with No. *3* on dynamo *B*, using the switchboard represented in Fig. 48, Art. **115,** and starting with it in its present condition?

(21) A four-pole shunt-wound motor is installed in a certain shop, but on trying to start it, it is found that no current will flow through the field coils, although the circuit to which they are connected is alive. (*a*) What is the trouble? (*b*) How may it be located?

(22) (*a*) What three general methods of regulation are used with closed-coil constant-current dynamos? (*b*) Which of the three is most generally used?

(23) In a certain three-phase alternator, at a certain instant, the current flowing out through one of the brushes is 10 amperes, and the current flowing in through another brush is 39 amperes. (*a*) What is the strength of the current flowing in or out through the third brush, and which way is it flowing? (*b*) What makes you think so?

(24) How is it that the current taken by a synchronous single-phase motor can vary with the load, although the number of revolutions per minute does not vary?

(25) A certain motor, being tested with a Prony brake, is found to have 85% efficiency when taking an input of 33 amperes at 230 volts. If the arm of the brake is 2 feet long, from center of shaft to point where it rests on the scale platform, and the pressure on the scale platform is 20 lb., at what speed (to the nearest whole revolution) is the motor running? Ans. 1,136 rev. per min.

(26) What would be the frequency of the alternating current furnished by a 14-pole alternator running at 1,080 revolutions per minute? Ans. 126.

(27) (*a*) For what purpose is a lightning-arrester used? (*b*) How does it work?

(28) Why is the starting resistance of a shunt motor not included in the field circuit?

(29) How is it that the magnetic field of a rotary-field motor rotates?

(30) How may a grounded field coil in a shunt-wound generator be located, the current from another similar dynamo being available?

(31) (*a*) What is a multiphase alternator? (*b*) How does the current it furnishes differ from that of a single-phase machine?

(32) How is an alternator compounded?

(33) How may a path be provided over which the static electricity which may accumulate on a dynamo frame escapes?

(34) In general, what is the object of a switchboard?

(35) Why is it that there is no E. M. F. generated in the coil of a Westinghouse constant-current dynamo which is directly under a pole-piece?

(36) What is the general principle upon which all electric motors operate?

(37) What are bus-bars, and for what are they used?

(38) Why will an armature of too low resistance give little starting torque in a rotary-field motor?

(39) What is the character of the current in the external circuit of open-coil constant-current dynamos?

(40) For what purpose is the equalizing connection used in connecting compound-wound dynamos in parallel?

(41) On starting up a dynamo, one of the bearings begins to heat badly, and on examination it is found that the shaft is dented in places and has several rough spots. How may these defects be remedied?

(42) Why is it that the speed of a shunt-wound motor varies very little from full load to no load when supplied with a current at a constant potential?

(43) What is meant by a burned-out armature coil?

(44) How may an armature be balanced?

(45) Why does the neutral line of a motor shift in the opposite direction to that of a dynamo?

(46) Why should the ammeters on a switchboard for compound-wound dynamos, to be run in parallel, not be connected in the side of the circuit in which the series coils are connected ?

(47) What limits the output of constant-current dynamos ?

(48) What losses occur in a static transformer ?

(49) What are some of the advantages of magnetic-circuit breakers as compared with fuses for use on switchboards ?

(50) What would be the successive combinations which any particular coil in the Thomson-Houston constant-current dynamo makes with the other coils during a half revolution, starting from a position where it is not active ?

(51) How does armature reaction affect the output (*a*) of synchronous alternating-current motors ? (*b*) of rotary-field motors ?

(52) A certain shunt-wound motor takes a current of 5 amperes at 125 volts when running free. Its armature resistance is .04 ohm and its field resistance 62.5 ohms. (*a*) What would be its output in H. P. when taking a current of 77 amperes at 125 volts ? (*b*) What would be its efficiency at this output ?

NOTE.—As the method of finding the output and efficiency which should be used in solving the above problem is not strictly accurate, four figures are enough to retain in calculations or results.

Ans. { (*a*) 11.76 H. P.
{ (*b*) 91.17%.

(53) What is the effect of too much oil or grease on the commutator of a direct-current constant-potential machine ?

(54) (*a*) Why should the armature coils of an alternator be no wider than the neutral spaces ? (*b*) Why should the neutral spaces in an alternator be made of the same width as the fields ?

(55) How is the E. M. F. of the Excelsior constant-current dynamo regulated to give a constant current ?

(56) What becomes of the energy in a direct-current motor armature represented by the product of the current flowing and the counter E. M. F. ?

(57) (*a*) By what two general systems is the current for incandescent lighting distributed ? (*b*) Describe the essential features of each method.

(58) What would be the speed at full load of a rotary-field motor whose field winding has 10 poles, if supplied from a circuit whose frequency is 72, assuming 2.5% slip ?

Ans. 842.4 rev. per min.

(59) Suppose that on starting a shunt-wound dynamo it should refuse to build up. What would probably be the trouble, and how would it be remedied ?

(60) (*a*) When a current is sent through a direct-current armature which is in an excited field, why does the armature tend to rotate ? (*b*) Under what circumstances will it rotate ? (*c*) Why does it not continue to speed up indefinitely when it has once started ?

(61) In what position with reference to the pole-pieces are the armature coils of a drum-wound alternator when there is no E. M. F. generated in them ?

(62) Why should both parts of the magnetic circuit (field-magnet and armature core) of a rotary-field motor be laminated ?

(63) Why is it necessary to use multipolar field-magnets for alternators ?

(64) In what general respects do switchboards for incandescent-lighting circuits using alternating currents differ from those using direct currents ?

(65) To reverse the direction of rotation of a direct-current motor, what changes in the connections are necessary ?

(66) Suppose that one of the field coils of a shunt-wound four-pole direct-current dynamo is wrongly connected. What effect would this probably have on the E. M. F. ?

(67) To what classes of work are (*a*) shunt-wound direct-current motors applicable? (*b*) series-wound motors? (*c*) Why?

(68) Describe the method of shifting the brushes used in the Thomson-Houston constant-current dynamos.

(69) What is a water rheostat, and for what is it often used?

(70) How is it that the armature winding of a rotary-field motor has no connection with the external circuit?

(71) On what conditions does the torque of a direct-current motor depend?

(72) Why does closing the secondary circuit of a transformer increase the current in the primary?

(73) What is meant by the "slip" of a rotary-field motor?

(74) Make a sketch showing your idea of the proper arrangement of the apparatus and the principal connections on a switchboard for a plant employing three compound-wound direct-current dynamos which are to be run in parallel and are to supply seven lighting circuits.

(75) Describe the general features of the Prony brake.

(76) Why is it desirable that the width of the open space between the two active parts of an armature coil of a drum-wound alternator should be not less than the width of the field?

(77) A single-phase alternating-current synchronous motor whose field has 22 poles is supplied with an alternating current with a frequency of 132 cycles per second. At what speed will it run? Ans. 720 rev. per min.

(78) (*a*) Why is it desirable to use an external resistance in the armature circuits of a rotary-field motor? (*b*) Why is this resistance not left permanently in circuit?

(79) How is it that the brushes of a constant-current dynamo with a closed-coil armature may be shifted to a considerable extent without causing excessive sparking?

(80) How may the applied E. M. F. of a direct-current motor be varied?

(81) From the nature of the sparking, how can you tell whether the brushes of a direct-current constant-potential dynamo are too far forwards or too far back?

(82) How are the devices for shifting the brushes of constant-current dynamos with closed-coil armatures usually thrown into or out of action?

(83) A three-phase rotary transformer is to deliver current at 200 volts. What must be the voltage of the alternating current supplied to it? Ans. 122.4 volts.

(84) An alternating current whose curve is of the form shown in Fig. 17 or 18, and whose maximum value is 12 amperes, is passed through a length of fine copper wire which it heats to a certain temperature. (*a*) What would be the number of amperes of a (steady) direct current that would heat the same wire to the same temperature under similar conditions? (*b*) Why? Ans. (*a*) 8.48 amperes.

(85) Why will the speed of a direct-current motor increase if the field is weakened?

(86) What is phase splitting?

(87) State two of the methods used in starting polyphase synchronous motors.

(88) How may the direction of rotation of a polyphase induction motor be changed?

(89) How may a two-phase induction motor be used on a single-phase circuit?

(90) What will be the alternating E. M. F. supplied by a two-phase rotary transformer fed with direct current at 220 volts? Ans. E. M. F. of each phase, 155.5 volts.

(91) How may the E. M. F. of the direct current supplied by a rotary transformer be varied?

(92) Referring to Fig. 16, Art. **34**, what will be the E. M. F. between *1* and *4* if the voltage on each phase is 440 volts?

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